2019

Agent-Based Simulation of Artificial-Intelligence-Assisted Transfer of Care

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AGENT-BASED SIMULATION OF ARTIFICIAL-INTELLIGENCE-ASSISTED TRANSFER OF CARE

A thesis submitted in partial fulfillment of the
requirements for the degree of
Master of Science in Industrial and Human Factors Engineering

by

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2019

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GRADUATE SCHOOL

April 22, 2019

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY PAUL B STONE ENTITLED AGENT-BASED SIMULATION OF ARTIFICIAL-INTELLIGENCE-ASSISTED TRANSFER OF CARE, BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INDUSTRIAL AND HUMAN FACTORS ENGINEERING.

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ABSTRACT

Stone, Paul B., M.S.I.H.E, Department of Biomedical, Industrial and Human Factors Engineering, Wright State University, 2019. Agent-Based Simulation of Artificial-Intelligence-Assisted, Transfer of Care

This study demonstrates the application of Agent-Based Simulation as a potential training aid for Transfer of Care (ToC) between EMS and a hospital triage department. The specific aim was to develop a simulation to increase the efficiency and accountability of information communication during ToC to test the suitability of Agent-Based Simulation to address training requirements in complex, health provision settings. This paper focuses on the design of the training simulation, including the development of individual agents within the simulation through the user interface elements and the evaluation and verification of the prototype simulator. The primary objective is for the simulation to generate realistic scenarios including complex and non-repeating patient conditions and outcomes based on real-world data and to provide an interface for trainees to conduct a simulated ToC task. It is hypothesized that an agent-based ToC simulator will provide a representative model of emergency situations both in realism and complexity. The study showed Agent-Based Simulation is capable of producing highly complex representations of healthcare scenarios and the prototype simulator was found to be statistically representative of real-world data. This paper primarily presents the work related to the simulation design and development and an initial validation of some model elements using the NEMESIS database.

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ACKNOWLEDGMENTS

This work is funded by Ohio Federal Research Network (OFRN) and Wright State Research Institute (WSRI). I would like to thank Drs. Ali Reiter and Sarah Napier and Colonel Douglas Hodge, USAF, Retired, Wright State Research Institute, for their technical expertise, and the University of Utah, NEMSIS Technical Assistance Center, for the provision of the public version of the NEMSIS database.

I would like to thank my Advisor, Dr. Subhashini Ganapathy, for her support throughout the project and assistance in setting up the relationships with WSRI and the National Centre for Medical Readiness. I would also like to acknowledge the contributions of those involved in the early phases of the work, particularly Uttam Karki for his work on the POMDP model that underpins the Patient Agent component.

I would like to thank Julie Anderson for her support and understanding during the completion of this study; I couldn't have done it without you! Finally, I would like to thank my parents and family for all they have done for me; I would not be here today without you.

Make tiny changes to earth.

—Scott Hutchison

1. Introduction

This work is funded by Ohio Federal Research Network (OFRN) and Wright State Research Institute (WSRI). This paper details the development of an Agent-Based Transfer of Care simulator for training healthcare professionals to improve communication skills, specifically associated with patient handoff. The rationale for the development of improved training in Transfer of Care is summarized in the introduction of the RLVC Requirements Document (2016) as follows:

> Medical errors have been recognized as the third leading cause of death in the United States by researchers at Johns Hopkins Medicine. It has been estimated that 250,000 Americans die annually due to medical error, and "an estimated 80% of serious medical errors involve some sort of miscommunications" (Ash, J.S. 2003). At present time, handover communications, a type of face to face communication that pertains to the patient's current condition, recent changes in condition, treatments that have been given, and potential complications that result from those treatments, are a significant method of transfer of care. As each handover relies on the discretion of the healthcare workers at hand, the chance for miscommunication or underreporting of information increases with each handover. These handoffs occur throughout the continuum of care.

Information transfer in patient handoff remains an understudied area, as indeed is the wider problem of face-to-face information communication between humans. The RLVC Requirements Document (2016) notes the piecemeal nature of support systems and Transfer of Care protocols across the healthcare systems and providers, even at a local level. It is noted that not only can this damage patient outcomes, but it can become difficult to scientifically track the cause of these outcomes and design systems and training procedures to address the underlying problems (RLVC Requirements Document, 2016). Horwitz, Moin, Krumholz, Wang, and Bradley (2008) note that the problem of communication during Transfer of Care is a significant issue as poor patient information transfer results in poor Transfer of Care, which can negatively impact healthcare, threatening patient's health itself or delaying patient recovery.

In addition to this, Transfer of Care is a complex, dynamic, and time-critical problem, all of which can contribute to degraded human-to-human communication performance (Belkin, 1984). Current training of healthcare professionals, from EMTs to paramedics and triage professionals, focuses on skill-based aspects such as the diagnosis and treatment of injuries and conditions. Part of training in knowledge transfer is understanding the information requirements throughout the patient handoff process, and part is developing the cognitive skills needed to achieve this, such as improved memory commitment and recall and improved information prioritization. This process is currently passed on from senior staff to trainees with no formalized or standardized method to improve performance, as are in place for most skill-based aspects of the roles. As such, there is a potential to improve knowledge-based training to improve Transfer of Care (RLVC Requirements Document, 2016). One potential solution to improve training in information transfer is simulation. Cabrera, Taboada, Iglesias, Epelde, and Luque (2011) note that simulated learning environments can provide the potential for knowledge improvement if suitably representative of the complex, dynamic and time-critical nature of Transfer of Care.

This study focuses on the application of Agent-Based Simulation in the development of a Transfer of Care simulator. Agent-Based Simulation is an emerging alternative to discrete-event modeling of complex, dynamic systems that could underpin such a training simulator. The technology offers the potential for increased complexity within simulations and improved realism representing humans in such systems. Su, Yang, and Jin (2008) studied the application of Agent-Based Simulation in a medical environment and concluded that the approach can be an effective part of modeling complex systems involving human decision making. Where discrete-event modeling makes top-down, system-based rules, the Agent-Based approach focuses on behavioral rules of individual “agents” to build complex systems from the bottom up (Cabrera, Taboada, Iglesias, Epelde, & Luque, 2011). Agent-Based Simulation in healthcare is discussed by Cabrera et al. (2011), noting the explicit ability of such systems to model complex real-world interactions as in the healthcare applications. Moss and Davidsson (2001) note that Agent-Based Simulation is particularly useful for modeling social interactions, arguing that the complexity of the underlying model is vital to achieve realism within a simulated environment containing representations of humans. Further to this, Borshchev and Filippov (2004) suggest that the Agent-Based approach is capable of capturing more real-world phenomena with greater variance than other approaches such as discrete-event modeling. This is especially true if the states and behaviors can be suitably defined and quantified (Railsback, Lytinen, & Jackson, 2006). Discrete-event modeling can have advantages, especially when the simulation is required to consider specific combinations of events with known or estimable probability of occurrence. However, for simulations with active elements such as people or animals, designers should consider the Agent-Based approach (Borshchev & Filippov, 2004). Agent-Based models are scalable, from simple models to complex System of Systems (SoS) models (Soyez, Morvan, Merzouki, & Dupont, 2017). Sahoo, Mohapatra, and Wu (2016) have proposed a stochastic forecasting model to predict patient health status with an accuracy of about 98%. Utilizing data from a healthcare management system Sahoo et al. generated a correlation model, which in turn was used for forecasting. Similarly, Pham, Tran, Phung, and Venkatesh (2017) demonstrated a deep learning approach, predicting future medical outcomes based on historical medical records and previous illness history, inferring current illness states.

Transfer of Care is the transfer of a patient from one agent (referring) to another (receiving). Those agents can be Emergency Medical Teams (EMT), physicians in trauma centers, medical center nurses, and so on. Accurate and timely transfer of information plays a key role in ensuring safe ToC. Poor patient’s information transfer may result in poor Transfer of Care, leading in turn to additional healthcare cost, extension of patient recovery time, and threat to the patient's life (Pham, Tran, Phung, & Venkatesh, 2017). It is believed Transfer of Care can be better modeled and understood through the Agent-Based approach and as such will be the focus of this study. Losing track of patient information, transferring misleading information, and communication breakdown are all problems that can occur during patient handover. Additional focus is needed when transferring information in emergency situations due to time pressure and the potential criticality of the situation. Training simulation and automated handover procedures are ways to mitigate these risks and ensure successful Transfer of Care; however, accurately representing the complexity of this system in training and simulation is both difficult and resource intensive.

Two specific model types, the Markov Decision Process (MDP) and the Partially Observable MDP (POMDP), were selected for use in the simulation. The MDP models the problem of unpredictability in how the world changes as a result of actions (Karnon, 2003) and was utilized in the prediction of future patient states. POMDP is a decision-making tool applied for making beneficial decisions under a given set of most recent observations and is an extension to an MDP (Givon & Grosfeldnir, 2008). Instead of making decisions based on the current perceived state of the world, the POMDP maintains a belief, or probability distribution, over the possible states of the world, and makes decisions based on the current belief (Roy, Gordon, & Thrun, 2005). POMDP had gained popularity due to its capability to predict the future states and plays a great in optimizing the objective function. Lane (1989) used POMDP for modeling an optimization model for fisherman to yield maximum net operating income. The objective of POMDP is to find optimal actions to be taken yielding a maximum reward or, in other words, providing an optimal solution to the objective function (Lane, 1989). The basic framework of POMDP consists of an environment, agents, set of states, set of actions, rewards value, transition between states, and, unlike MDP, a belief state (Lane, 1989). Every action makes changes on the current state, determined by the probability function, which will yield the immediate reward value. The overall goal of the entire model is to maximize the summation of the rewards.

This project aims to demonstrate the application of Agent-Based Simulation to increase the efficiency of information communication during ToC. The specific objectives of the project were to develop an Agent-Based Simulation of the Transfer of Care process to enable assessment of EMS professionals in a training context. The simulator was designed to represent a simple Transfer of Care scenario with an integrated Artificial Intelligence (AI) agent to provide dynamic information prompts, automatic data entry, and intelligent, scenario-dependent feedback on decisions made in the information transfer task. The project consisted of two test scenarios – on the first, all patient information is generated by the simulation and then collated and transferred by the paramedic team (control condition) and in the other, an AI was used to assist the participant information handover (experimental condition). This paper presents the work related to the design and development of the simulation model and an initial validation of the model using the NEMESIS database. The simulation was developed in C# because of its object-oriented feature set and ease of cross-platform development capability.

The concepts and functionality that underpin an Agent-Based Simulation can be built into a rule-based architectural framework as described by Suwa, Scott, and Shortliffe (1984). The authors note that, when designing such an architecture, the completeness and consistency of both contributing data and the logic rule set used in the framework, as well as systematic debugging of such systems, are important to ensure they operate as intended. They define a structured process to identify all rules defined in the program and the contributing variables or data that are required. Their study implements this approach in an oncology consultation decision tool, but the approach is flexible enough to be used in any rule-based architecture as a potential Transfer of Care simulator.

As this is a prototype simulation, there is no requirement for a formalized architectural type or release structure. However, Van der Hoek, Heimbigner, and Wolf (1998) described the importance of structured architectures, and where possible, the protocols and norms identified will be followed to ensure the Transfer of Care simulation is robust and the development process results in compatible updates. Abowd (1995) describes the formalization of software architecture elements into components, connectors, and configurations. The components perform the calculations within the software, connections transfer information between the software, and the configuration describes how these elements are arranged. Fu and Fu (1990) discuss how to map rule-based systems into software architecture, suggesting maintenance of structural and behavioral components that are designed and arranged in line with existing frameworks or organization hierarchies of the system being modeled.

At the core of this study is the problem of optimizing information transfer between two humans in a time-sensitive situation. Belkin (1984) discusses and defines what is meant by information transfer as well as the requirements for effective information transfer. Information transfer is defined as the dynamic interaction among three components: the user, the knowledge resource, and the intermediary mechanism between the first two components (Belkin, 1984). This case assumes the user is attempting to retrieve information from a non-human system. The Transfer of Care situation involves the same three components where the user is the receiving agent, and the resource is the transferring agent, or EMS professional. The intermediary mechanism simplistically is human verbal communication, but in the modern patient handoff environment, it could be via written or digital communication platforms. Belkin (1984) goes on to define effective information transfer as information that results in the user being better able to understand and/or manage the problem that initiated the information. Belkin (1984) establishes the importance of cognitive models in enabling effective information transfer, and this forms the premise of the approach taken in this study.

The belief underpinning the research is that providing timely and accurate feedback on the quality and completeness of information given can reinforce users' cognitive models of the information they have, the information they need to impart to the receiving user, but also the expectations and requirements of the second user. This approach means the intermediary mechanism can be independent of effective information transfer, as long as it provides adequate bandwidth or descriptive power. Wayne et al. (2008) define a simplified approach to intra-hospital patient handover and demonstrated statistically significant improvements in both accuracy and completeness of information transfer with a simple, low-tech approach. It is believed that developing systems to improve user's cognitive models of patient handover could offer similar improvements in accuracy and completeness of information, without the need to simplify or reduce the amount of information transferred. The effectiveness of closed loop or feedback-reinforced learning has long been established. Adams (1971) discusses the performance of closed loop learning systems on physical activities allowing more frequent, more precise, more immediate, or more "useful" learning outcomes. Nicholson and Schmidt (1991) also examine the importance of feedback in information-based training systems and conclude that maximizing the immediacy of feedback is key to effective learning. Wentworth et al. (2012) designed an electronic system to improve Transfer of Care in non-complex patients. But there is still an apparent requirement—and there will always be a requirement—for a human user to input data in emergency scenarios and improved training and development of cognitive models can impact even a highly automated system and provide additional attentional resource for transferring and receiving agents. It is believed that a closed loop training system can provide the consistency associated with a digital system but also enable EMS professionals to operate more efficiently and enable more accurate and complete Transfer of Care.

Heuristic evaluation will be the primary means to evaluate the simulator during this phase of the study; however, the RITE method is also a potential option for assessment of the simulator development throughout the project. This method is described by Medlock, Wixon, Terrano, Romero, and Fulton (2002) as an agile usability assessment method that is particularly useful when there is a limited assessment population. The goal of the RITE method is to identify and fix as many issues as possible in short assessment cycles to enable verification of the changes (Medlock, Wixon, Terrano, Romero, & Fulton, 2002) and the authors claim that this method is potentially as effective as traditional heuristic evaluation.

1.1. Scope

1.1.1. Previous Work Definition

This thesis summarizes the third phase of a study into optimizing Transfer of Care through the use of Agent-Based Simulation for developing Transfer of Care training. The initial phase developed an understanding of the information generated within an emergency situation and a breakdown of the various elements from the perspective of an EMS professional. These are combined with task elements and synthesized into requirements for a Transfer of Care training platform. The output of this phase of the study is summarized in the RLVC Requirements Document (2016). The second phase of the study developed an initial prototype of an Agent-Based training simulator. The architectural configuration and synthesis of the rules used in this phase of the study were initialized in Phase 2 along with the initial UI configuration. Phase 3 covered testing and development of the simulator along with integration of refined rules and AI assistant enhancements. The treatment response model was refined and a new patient degradation model was integrated along with an EMS treatment prioritization model. The patient information display was updated from a literal readout of the model variables to a contextual, natural language engine to explain the initial patient condition and color-coded scaled indicators to express dynamic patient conditions and success probabilities.

1.1.2. Contributing Study Elements

This project covers the User Profile, Task Analysis, and Use-Case definitions, through to the human-centered design and development of a C#-based simulator developed in Visual Studio and the initial verification, validation, and usability testing through heuristic evaluation in expert user groups. As the target population is specific professionals, and as their profession is the dominant rationale behind the use of the system, personas were not utilized. An initial protocol for future human subjects testing is included, but this will not be finalized during this phase and results subsequently will not be reported here.

1.2. Aim

The aim of this project is to design and develop and test a prototype Agent-Based Transfer of Care simulator to provide immediate feedback and improve the accuracy and completeness of information transfer among healthcare professionals.

1.3. Objectives

The following specific objectives support the realization of this aim and broadly define the approach taken in the development of the simulator, the general methods used, and the work detailed in this paper.

- Review existing studies and emerging applications.
- Conduct systems analysis of the Transfer of Care process.
- Develop conceptual model for improvement of Transfer of Care through simulator training.
- Conduct Human Factors Analysis of the Transfer of Care process.
- Select appropriate platforms, configurations, and methods for design, build, and test of a simulator platform.
- Conduct an iterative, user-centered design (using the RITE method) and evaluation of the Transfer of Care training simulator Approach.

2. Task Analysis

Initial Task Analysis was conducted in consultation with Transfer of Care SMEs based at the WSU NCMR. Data was collected using structured task walkthrough interviews. For the interviews, users were asked to walk through the Transfer of Care process with probes to establish detail or clarify or isolate individual task components. No personal information was collected during the interview process. In addition to this, current SOPs and procedures were analyzed.

2.1. Hierarchical Task Analysis

The Hierarchical Task Analysis (HTA) considers the tasks specific to the information transfer between medical professionals. Care provision tasks are not considered in this analysis. Several specific assumptions are made in this task analysis: As the focus of this study is to build a simulator that does not currently exist and has, consequently, not been used by any medical professionals, this HTA is based on the existing real-world Transfer of Care process.

- The medical professionals involved in the Transfer of Care are familiar with protocols and procedures and any appropriate SOPs.
- Technical terminology is understood by all parties and detailed explanations of these are not required.

Full details of the HTA are given in Appendix A. The main findings of this process were that accurate recall by the transferring agent and the talkback protocol, where verbal confirmation of information transfer is given by both transferring and receiving parties, are key to information assurance. This aims to ensure that the receiving agent understood correctly and acts as a check for the transferring agent.

2.2. Analysis of Current Procedures and SOPs

The patient handoff SOP is outlined in *Standard Operating Procedure (SOP) for Patient Handoff Between a Healthcare Facility and a Transporting Ambulance* (2016). The information transfer aspect is a narrow task within this wider SOP. There is only a single line instruction in this SOP relating to information transfer: "Transfer patient care to receiving facility team as arranged (and exercised)." As with the HTA analysis, this just highlights the lack of formal structure in existing Transfer of Care protocols. More than just defining the framework and rules for information transfer, this information highlights the potential for more structured training and protocol definition in the process.

2.3. User Profiles

For this study, trainee EMT and triage professionals and military Medivac and receiving medics were considered to be the primary users of the simulator. This limits the potential user community, although it is still important not to exclude potential users if they do not fit the typical profile. The primary user profile defined in this section encompasses the range of attributes expected in this population. The user attributes defined in this section are based on assumptions made by the author and research conducted into specific user demographics through consultation with experts at the WSU NCMR. All these users will need to be physically fit enough to carry out their usual duties such that they would not have physical impairment that would limit their use of a laptop-based simulator. The results of the user profile analysis are detailed in Tables 1 to 4, with Table 1 representing the physical characteristics of the user, Table 2 the psychological characteristics, and Tables 3 and 4 the skill and job characteristics, respectively.

Table 1. Physical Characteristics

Attribute	Primary user	Implication
Vision (acuity)	Low to High. It is reasonable to expect users to be wearing corrective eyewear if needed.	Standard to large character size with adjustable contrast.
Vision (color blindness)	Yes	Color should not be primary coding.
Hearing (frequency)	Low to High. However, there may be situations where audio cannot be used.	Average hearing range and sensitivity can be assumed. However, if possible, this should be only a secondary information/alert channel, and other means should be used where possible.
Hearing (decibels)	ISO Standard	Based on background noise of approximately 105 decibels.
Gender	Male or Female	Core functions should be gender neutral. Gender split is 66.7% male, 33.3% female amongst EMS professionals in the US (142k male, 71k female) (Emergency medical technicians & paramedics | Data USA, 2016). Assuming Triage professionals are in line with other areas of nursing, the gender split is more pronounced, with over 90% female nursing staff (Rappleye, 2015).
Handicaps	Users with limited handicaps may be primary users.	Keep operation simple and easy with optional multi-fingered keystrokes. This will mainly impact physical or smartphone interface aspects of the design. Potentially control of functions could be speech activated to improve.
Age	18–60	Although primary users are likely to be early 20s, paramedics can start training at 18 and join into their 50s (Paramedic Training Spot, 2019).
Manual dexterity	Average to Above Average	No dexterity required above that of the ability to operate a laptop or tablet computer.

Table 2. Psychological Characteristics

Attribute	Primary User	Implication
Visual (textual)	Yes	Use text for clear, concise instructions.
Visual (graphical)	Yes	Use icons or pictures with text where possible.
Spatial	Yes	Minimize complexity—keep it simple.
Field-dependence	Yes	Minimize interface operational control clutter—keep menus/screens simple.
Auditory	Yes	Use auditory feedback when appropriate, but generally not as the primary modality.
Experiential	Yes	Keep it simple. Eliminate the ability to make mistakes or, if not, allow user to correct mistakes. Reduce memory load where possible.
Attitude	High	Make the product engaging—needs to be operationally effective but is reliant on user attitude to ensure engagement and mental-models are reinforced.
Motivation	High	There is intrinsic engagement with health professionals wanting to deliver higher quality of care and patient outcome.

Table 3. Knowledge, Skills, Attributes, and Characteristics

Attribute	**Primary User**	**Implication**
Reading level	Seventh grade	Write instructions to seventh-grade reading level (national average).
Education	High school and above	College education is assumed. Use simple non-technical jargon – use wording familiar for everyday use.
System experience	Medium to advanced	Make process intuitive and simple to follow—menu screens that give clear instructions. Some knowledge of app layout can be expected.
Task experience	Novice to advanced	Make task simple and intuitive.
Platform experience	Low to medium	Make process simple and intuitive, Motivation is likely to be high, but user experience should be satisfying.
Native language	English/medical technical	It can be assumed that all users will have English-language knowledge and knowledge of medical terms. Removal of medical technical terminology from the simulator could limit the effectiveness of the platform. Specific military or Spanish-language versions could easily be adapted from the initial prototype.
Use of computer systems	Medium to high	Avoid technical computer jargon—use platform that is familiar to all (Windows/Android/IOS). The product is for medical professionals.
Computer literacy	Low to high	Avoid technical computer jargon – use technical medical terms and natural language.
Training	No formal training, instructions only	Make process intuitive and provide screens to guide work. Provide clear instructions within the simulator and assume no tutor is present.

Table 4. Job and Task Characteristics

Attribute	**Primary user**	**Implication**
Frequency of use	Low to medium	Use in initial training and for transfer to a new role (as a training application). If the secondary use case was adopted, this is a tool that could be used daily.
System use	Routine	Must be intuitive, engaging, and effective.
Urgency of task	Routine Urgent	Use as a training aid would not be time sensitive. Use as a decision support aid would be time critical and require much greater accuracy and utility assessment.
Other tools needed	Laptop	Easy to install.
Task importance	High	Both as a training platform and a decision support tool.
Task structure	High	Provide intuitive and easy-to-understand process and operation
Environment (noise)	Low to high	Background noise—siren mean maximum of 102.5dB (Johnson, Hammond, & Sherman, 1980)
Environment (lighting)	Low to high	Visual requirements should reflect complex nature of environments—twilight to unobscured sunlight. Natural lighting, 10 to 100,000 lux. (Spitschan, Aguirre, Brainard, & Sweeney, 2016).
Availability of the user	High Medium-low	As a training aid, the users will have their full attention on the systems Decision support—minimize memory load, maximize persistent (visual) information channels as primary sources. Although users are professionals, their attention will likely be at best partial on such an app.

2.4. Use Cases

The aim of the use cases identified here is to define the situations in which users of the system will be expected to operate the Transfer of Care simulator. Based on the output from the task analysis, the use cases inform both requirements definition and the development of potential scenarios for usability, utility, and quality assurance testing. As the simulator is a training platform, there are a limited number of use cases outside of that core function as additional design elements could distract from this purpose. There is potential for the concept to be used both as a training aid and, in the future, as a decision support tool; so this additional use case is also considered to ensure that compatible goals and requirements are derived. These use cases are adapted from those defined in the RLVC Requirements Document (2016) to reflect more generic scenarios and greater focus on the Transfer of Care element of the problem space, and to have greater applicability to a range of scenarios both civilian and military.

2.4.1. Functional Learning (core Use Case)

Use Scenario: The simulator is envisioned as an initial training aid to foster the rapid development of cognitive models of information transfer among inexperienced EMS professionals or those in the early phases of training. The existing simulator is aimed at EMS professionals, but the functionality could be implemented for triage professionals, although this would not require additional use-case analysis. The simulator is designed to be complex enough to provide dynamic and engaging scenarios that do not repeat. This means that each iteration of the trainee using the simulator tests their ability to build a cognitive model of the information transfer process and implement it, rather than simply conducting a memory task on a narrow, deterministic simulation.

Training agent: EMS trainee

Actors: All virtual agents within the Transfer of Care simulation, EMS training assessor.

Use Case Overview: Trainee EMS professional is developing information transfer skills prior to commencing practical aspects of the training.

Basic Flow:

1. Load Simulator program.
2. Login/provide user details.
3. Initiate simulation—click on the start button.
4. Observe as an emergency situation is developed by the simulator, actioning treatments as indicated.
5. As the information develops, remember and prioritize the most salient information believed to be required to achieve effective transfer of care.
6. Once the simulation phase is complete and the virtual patient has arrived at the hospital, move on to the information transfer phase.
7. Using memory alone, enter the user's belief of the patient details and characteristics into the simulator's input form.
8. Submit Transfer of Care details to the virtual triage professional.
9. Receive immediate feedback on the information transfer effectiveness.
10. Repeat this task as needed, developing internal strategies for maximizing information transfer effectiveness.

2.4.2. Decision support (secondary Use Case)

Use Scenario: The secondary use is where an EMS professional could utilize the information recording and patient prediction elements in an operational setting to augment the cognitive models developed in the training phase. Enabling a voice assistant would be key to the success of this type of use to ensure EMS professionals have minimal distractions or manual tasks that cannot be carried out during treatment of the patient.

Training agent: EMS trainee

Actors: EMS dispatch, patient, triage professional

Use Case Overview: EMS professional using the data recording and patient status prediction aspects as a decision aid.

Basic Flow:

1. Receive information from dispatch in the integrated messaging system within app.
2. Conduct EMS response as in any other situation—details omitted for clarity.
3. Use AI voice assistant to input patient condition, treatments, etc.
4. Utilize treatment prioritization engine where appropriate.
5. Monitor patient status prediction engine to provide additional information on potential patient state (based on real-world statistical data).
6. Provide enhanced information transfer to triage professional.

2.5. Requirements

The task elements defined in this task analysis were synthesized into user requirements and system requirements, which were then used to underpin the heuristic usability assessment and define metrics for quantitative assessment. A human-centered design process requires that these requirements are identified for both utility and usability elements of the problem space. Nilsen (1993) defines usability requirements as Learnability, Efficiency, Memorability, Errors and Satisfaction. These generic usability requirements have been modified for this study as follows:

- Learnability: How easy is it for trainees to use the simulator the first time they use it?
- Efficiency: Once users have learned the simulator operation, how quickly can they utilize the full functionality?
- Memorability: When returning to the simulator, how difficult is it to reestablish competency?
- Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
- Satisfaction: How pleasant is it to use the simulator?

The utility requirements are more qualitative in nature and relate to the accuracy and completeness of the transferred information. The time taken for Transfer of Care is another important aspect of the process and has a defined utility requirement.

2.5.1. User Requirements

The User Requirements are split into two groups: "must have" requirements, or Key User Requirements (KURs); and "should have" requirements. Each User Requirement has a unique User Requirement ID (URID) to enable links with System Requirements and usability testing. KUR IDs are prefixed with a "K" and other requirements are prefixed with a "U." Utility-based requirements are defined with the suffix "UT" and Usability with the suffix "US." User requirements for the simulator are detailed in Table 5.

Table 5. User Requirements

URID	User requirement definition
K1 - UT	The user must be able to enhance their cognitive model of the information transfer process in emergency transfer of care.
K2 - UT	The user must be able to use the simulator on commercially available computer equipment.
K3 - UT	The user should be able to identify positive and negative outcomes of the training application in a timely manner such that the error source is easy to identify, and their cognitive model can be updated.
K4 - UT	The user must be able to recognize the scenarios and understand the development of patient conditions as if it was a real-life scenario.
K5 - UT	The simulation must be able to generate variable and dynamic scenarios that are unpredictable by the user.
K6 - US	The user must be able to comfortably interpret visual instructions and information generated by the simulator
U1 - US	The user should not be able to make erroneous data entry or action commands that impact the aims of the simulation.
U2 - US	The user must be able to use the simulation with minimal instruction and without the need for guided tuition.
U3 – US	The simulator should be engaging to all potential users.
U4 – US	The user should not experience repetitive simulated scenarios
U5 – US	The user should have a satisfying visual and interactive experience, without undue frustration when using the simulator.
U6 - US	The user should be able to track their performance over time using the simulator.
U7 - US	The user should be able to read the display in all lighting conditions.
U8 - US	The user should be able to start using the simulator within 5 minutes without reference to any external instructional materials.
U9 - US	The user should be able to identify all iconography used in display with minimal effort.

2.5.2. System Requirements

The system requirements are the functional requirements that the system must include to enable the user requirements to be met. These are linked to the user requirements and will form the basis of usability testing metrics. System requirements for the simulator are detailed in Table 6.

Table 6. System Requirements

ID	System requirement definition	Linked URIDs
S1	The simulator must capture relevant aspects of emergency medical intervention.	**K1, K4, K5**
S2	LVC platform must capture relevant aspects of real-world communication conventions pertaining to medical care.	**K4, K5**
S3	The simulator must aid in emergency medical response and must help in decision support of medical care.	**K1, K3, K5**
S4	The system will generate complex and unpredictable, yet realistic EMS scenarios.	**K1, K3, K5, U4**
S5	The system will allow information input and assessment of performance independent of elements that could bias results. This includes provision for an interface that is not sensitive to phrasing in the input phase.	**K1, U1**
S6	The system will provide informative assessment of the accuracy, completeness, and time of the transfer of care.	**K1, K3, U6**
S7	The system will have a visual display capable of simultaneously or sequentially displaying all required information and the correct brightness and resolution and with color-coded information as required.	**K2**
S8	The system will provide means for storing training outcomes from previous attempts and tracking long-term performance.	**K1, K3, U6**
S9	The system must provide a user interface that allows real-time control and manipulation of simulation components.	**K2**
S10	The system will provide audio information where necessary.	**K2**
S11	The display will be capable of achieving a contrast with the background such that information remains legible in all potential viewing conditions.	**U7**
S12	The system will utilize familiar and standard iconography for all appropriate information. If there is no standard, principle of familiarity and metaphorical representation will be used.	**U9**
S13	The system will have a high usability rating.	**U3, U2, U3, U5, U7, U8, U9**

3. Agent-Based Simulator Development

3.1. Concept

The aim of this project is to develop an Agent-Based Transfer of Care simulator to enable EMS and triage professionals to improve their information transfer performance. To understand how the simulator will improve information transfer performance, it was first necessary to define the generic information transfer process and then design an improved method, highlighting the elements that the Agent-Based Simulation will need in order to achieve the aims of the study. Using this Agent-Based approach in the development of the training system is expected to enhance the information transfer process by improving decision-making and in EMS professionals by increasing exposure to complex Transfer of Care scenarios and providing immediate feedback on both successful aspects and areas for improvement. The parallel development of AI elements within the simulator will support the removal of unwanted, incorrect, and misleading information and improve the quality of data transfer in emergency situations, reducing EMS workload and making it adaptable for use as an operational support tool. Successful application of this solution could provide an improved transfer of care process as part of the wider healthcare system and might reduce the workload in triage departments and improving patient outcomes by improving the quality and timeliness of information transfer in medical centers.

3.1.1. Information Transfer Optimization

The Transfer of Care process can be graphically modeled as an information flow. There are four types of information within a generic Transfer of Care process. These can be defined as Required Information, Unwanted Information, Incorrect Required Information, and Incorrect Unwanted Information. The Information Transfer process can either communicate or fail to communicate each of these information streams as shown in Figure 1. The information transfer process is different for each scenario and can be represented by an ongoing iterative information gathering and assessment phase as the patient condition develops or medical tasks are performed. Once the information is gathered and the patient arrives at the Transfer of Care location, there is a subsequent information distribution phase, as shown in Figure 1.

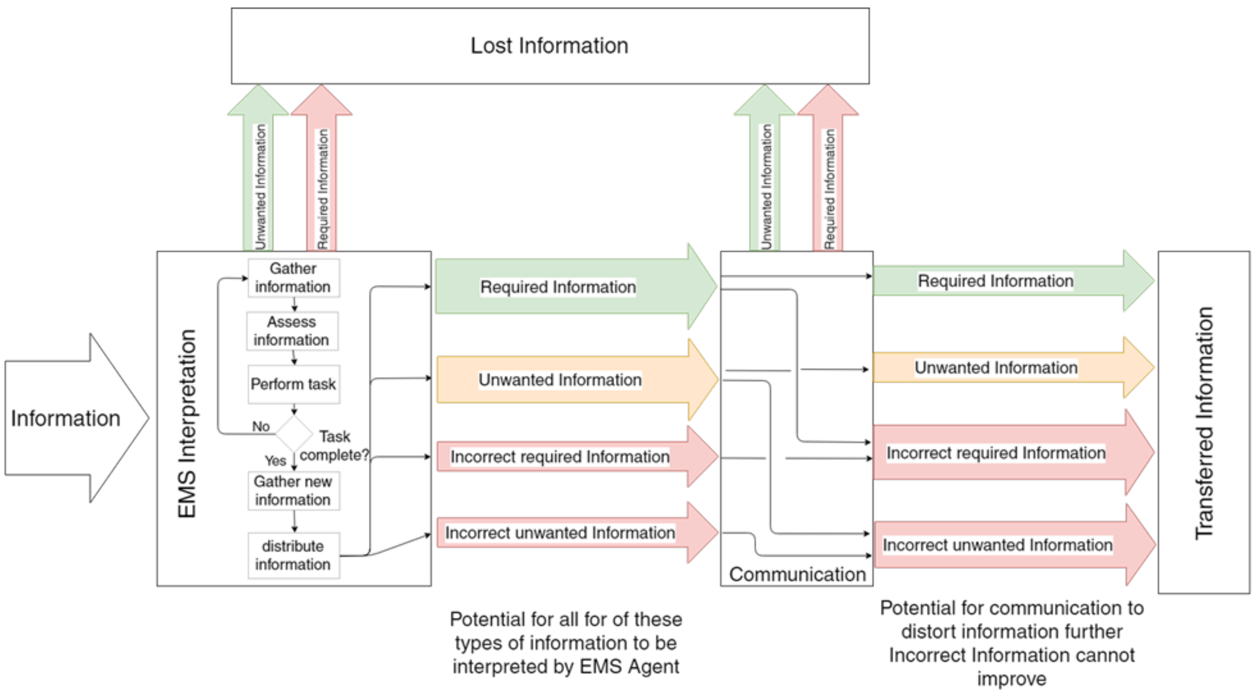


Figure 1. Suboptimal Generic Information Transfer Process

An Agent-Based training system would aim to improve the Transfer of Care process by providing dynamic, adaptive information requirement cues relevant to the specific scenario and by providing real-time feedback in both training and operational scenarios. The aim is to maximize the transfer of the 'Correct Required' information stream and minimize the others. As shown above, this is affected at both the information gathering and communication phases, both of which would be represented in the simulator. It is assumed that information can be lost or become incorrect only during the communication phase. The proposed improved information transfer process is shown in Figure 2.

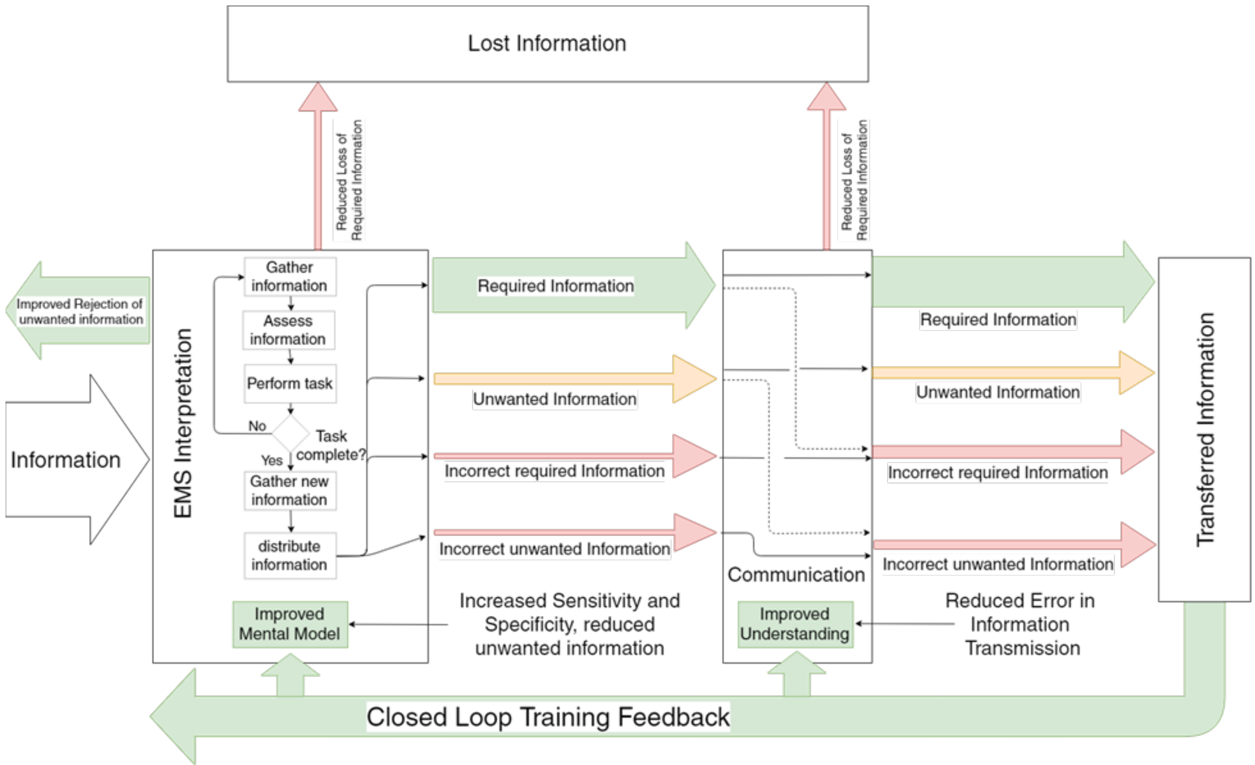


Figure 2. Improved Generic Information Transfer Process

To implement this, the aim is that the simulation provides complex and dynamic scenarios, representative of potential real-world scenarios, but the real-time feedback enables the user to build an improved mental model of the information requirements and would reinforce this by providing performance feedback and highlighting where errors are made. Underpinning the underlying model with realistic and validated agent behaviors, operational rules, and outcomes is vital to ensure that the useful mental models are developed.

3.2. Initial Design

This section outlines the initial design of the simulator. It contains descriptions of the components, connections, and configuration to give an understanding of the operation, but detailed explanation of rules is omitted at this stage to avoid duplication when discussing the final simulator design. The design needs to balance the need for a complex and rich simulation experience to maximize the usefulness of the training application, with the need to build a quantifiable model and operate within the limitations of the available data and the need to limit the dimensionality of the problem space to enable reasonable processing power to solve the problems in real time.

The key variables that will be used to develop the scenario are described, along with the levels and definitions of levels. These are assumed to be granular enough to achieve the objectives of the simulation but allow it to run. The simulator is designed to run at approximately 30 times real time to enable full scenario development without the need for a lengthy simulation that could run the risk of decreasing participant engagement.

3.2.1. Architecture

As the focus of this project is Agent-Based Simulation, this predefines the top-level architectural structure of the simulation, i.e., the components should be configured into logical agent categories with connections where needed to pass required information. In addition to this, the individual agents will have components within them that carry out sub-tasks. The components will be arranged according to real-life systems being simulated, i.e., the patient will contain the rule-based models intrinsic to a patient in a real-life scenario, and the rules and responses required of the EMS professional will be modeled by the corresponding agent in the simulation. This is both best practice as defined by Fu and Fu (1990) and a fundamental construct of the Agent-Based Simulation approach.

A prototype Agent-Based training simulation using Transfer of care between EMS teams and hospital triage as a testbed training scenario was developed. The training simulation is aimed at providing a training platform for EMS agents to improve information transfer skills. The premise of the training is that the trainee is presented with a complex EMS situation—for the initial prototype, a gunshot wound use case was defined, although the simulation structure and elements are designed to enable further expansion by adopting a modular MVVM configuration in the architecture. The simulation gives the trainee an overview of the development of the situation from first contact to the point of transfer. This is not currently in real time, as the aim is to simulate a dynamic and evolving patient state with realistic changes in patient state and associated treatments, which, without the actual treatment requirement, would be too long and have too little involvement to make an engaging simulation. The trainee observes this stage of the simulation, and once the simulation is complete, the trainee is to provide accurate information to a virtual triage agent. The simulation was built using virtual agents within the simulation to represent a patient as well as EMS and triage professionals. The EMS agent conducts treatment of the patient during the simulation, then the trainee takes on the role of the EMS agent for the information transfer stage. The aim of this design was to provide a fast and realistic information generation to underpin the information transfer training aspect of the simulation. In addition to these agents, the simulation contains an Artificial Intelligence agent, which can be turned on or off depending on the learning objective, and which provides additional decision support and information retrieval assistance for the EMS agent (trainee). The agent relationships in the scenario development simulation stage are shown in Figure 3.

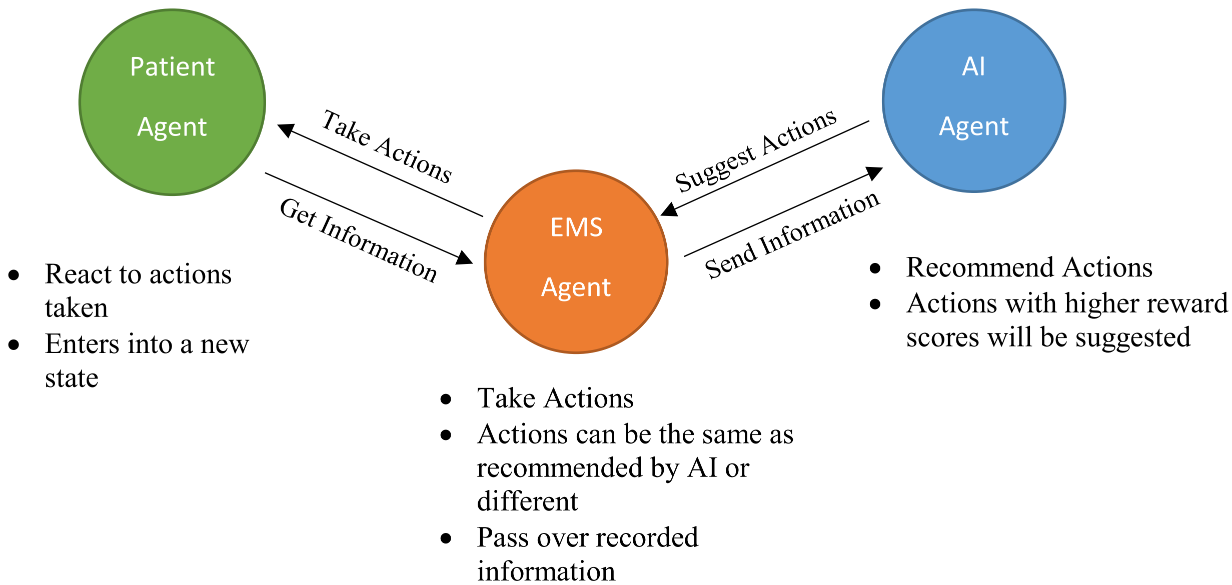


Figure 3. Agent Relationships in the Information Generation Stage

The underlying model needs to be presented to participants or prospective trainees in a manner that presents a realistic Transfer of Care environment and allows the assessment of information transfer both with and without AI enhancement in an unbiased and measurable way. This requires that the nature of the simulator itself does not provide an inherent advantage to either proposed solution. To achieve this, the simulation was designed to display an interactive EMS scenario and require the user to observe and develop a mental model of the Transfer of Care information and then transfer this information back into the model via an automated triage or receiving agent.

3.2.2. Patient Agent

The purpose of the patient agent is to provide the baseline truth patient condition for use in both the information generation and assessment phases of the simulation. The following patient metrics were selected for the Transfer of Care simulation to assess the quality and completeness of the Transfer of Care both with and without an AI assistant. These are representative of a generic Transfer of Care procedure drawn from the procedure identified in the RLVC Requirements Document (2016) and the TCCC card, DOD (2014). The metrics used are a subset of those available to enable a proof of concept prototype to be built in the time available. Table 7 contains the proposed metrics, and associated weighting for each aspect of the transfer of care process.

Table 7. Transfer of Care Metric Weighting

Metric	Description
(information metrics)	
Criticality	Overall patient state?
Circulation	Heart function?
Hemorrhage	Level of bleeding of the patient?
Breathing	Does the patient have breathing difficulties?
Airway	Is the patient’s airway blocked?
Consciousness	What is the patient’s level of consciousness?
Injury type	What was the initial cause of the injury, e.g., gunshot?
Injury location	Where on the patient was the injury sustained?
Age	What age group does the patient belong to?
Gender	Is the patient male or female?
(time metrics)	
Time to complete process	How long did it take to transfer the patient information?

The patient agent state defines dynamic patient characteristics for Circulation (heart function), Hemorrhage (bleeding), Breathing, Airways and consciousness on a three-point scale from 0 to 2, with 0 being no problem in the characteristic, 1 being minor problems and 2 being serious complications. This scale is consistent across all the patient function characteristics, as having a limited and standardized scale allows for easier assessment of the information transfer quality without bias implicit in different scales. The decision to sacrifice potential realism for ease of calculation was made for prototype development but could be reversed in a released version of the simulation.

The patient agent is a POMDP model where the patient state is assigned start conditions based on distributions derived from the National Emergency Medical Service Information System (NEMSIS) database, and the final patient state is dependent on the interactions with the EMS agent throughout the simulation. The patient agent is initialized with these characteristics determined in line with the related probability distributions and are interrelated and reflect real-world probabilities of a specific patient type being exposed to the injury type and severity. The use of the partially observable model in this case is representative of the fact that the patient condition will vary depending on the success of the EMS agent intervention which is a stochastic interaction. The patient agent is continuously updating its "state" throughout the simulation model where "states" refers to the overall patient health state as well as individual health characteristics. Improving the individual health variable metrics will result in incremental improvement of the overall patient status and vice versa. The patient agent contains both degradation and improvement logic, both of which are influenced by interaction or lack thereof with the EMS agent within the simulator.

NEMSIS is a national database that contains real-world data from over 40 million EMS events detailing timelines of injury, treatment, and outcome in each case. A random subset of the public version of the database was used to determine the probability distributions that underpin these patient improvement and degradation models. A training data set of 250,000 events was used to build the initial model, and a corresponding test set, also with 250,000 events, was used to confirm the model performance. The patient agent state is subject to continuous change based on distributions derived from this database.

3.2.3. EMS Agent

The purpose of the EMS agent is to provide independent interventions from the patient model that represent the potential actions of EMS in a real-world emergency without the need for the simulation participant to provide detailed intervention instructions. This is to ensure the focus of the simulation is the Transfer of Care information rather than the provision of the care. The EMS agent interrogates the patient agent and provides rule-based interventions with probability of success dependent on the patient characteristics, injury severity, number of previous attempts, and time since injury. In the case of multiple injuries, only a single intervention can be actioned by the agent at a given time. The interventions are based on SME expertise and probability of success derived from the NEMSIS database. The simulation will require the participant to acknowledge each action, whether successful or not, so that they develop an overall picture of the patient conditions and interventions prior to the information transfer phase.

3.2.4. AI Agent

The simulation provided both a standard and an AI-assisted scenario to assess the impact of AI. The AI provides direct assistance to the training participant to enable more informed and timely decisions on information transfer. The AI agent utilizes an MDP model to predict any likely changes to patient condition based on probabilistic models derived from the same NEMSIS data as the patient POMDP model. It was hypothesized that this would allow for more accurate estimation of future patient condition and potentially reduce the workload in training participants, enabling greater situational awareness and more efficient information transfer. Second, the AI agent provided real-time assessment of the completeness and any potential conflicts or inconsistencies in the information submitted. This was a rule-based assessment designed to ensure information regarding injury, patient state, and individual characteristics were in line with expected rules. Initially, the simulation contained simple and limited rules designed in consultation with SMEs at the Wright State National Center for Medical Readiness (NCMR). A more detailed simulation could include a more detailed, dynamic model but would require more detailed information on emergency scenario timelines. The user interface for this AI agent was an integrated voice assistant extension within the C# Winforms design environment in Visual Studio.

3.2.5. Initial User Interface Design

The simulation UI will consist of two primary interaction phases. First, participants will conduct the pre-transfer phase of the assessment. In this phase they will be presented with patient agent metrics developed in the stochastic model. This phase is intended to represent the timeline from EMS arriving on the scene to the point of arrival at the hospital or secondary care facility. Participants will be asked to monitor patient condition, and in the case of a change in patient condition, they will be prompted whether or not to provide specific treatments. In this phase, the AI assistant will give voice feedback rather than visual and allow hands-free recording of patient conditions and treatments given as well as giving a real-time prediction of any likely change in patient state.

The simulation uses the partially observable Markov Decision Process (POMDP) to simulate dynamic and complex behaviors of the patient agent and associated responses/treatments for the EMS agent. The patient behaviors are underpinned using real-world data from the National EMS Information System (NEMSIS) database, to generate probability distributions for injury types and specific health characteristics. This is simplified in the simulation to just Hemorrhage, Breathing, Heart Function, Airways, and

Consciousness. These characteristics, as well as being driven by real-world data, can be affected by actions of the EMS agent. The EMS agent is designed to react to the condition of the patient agent using rules derived from EMS operating procedures and task analysis. The aim of these design elements is to provide interactive scenarios and a realistic but measurable training environment for the transfer of care process. The initial design of phase 1, pre-transfer scenario generation interface, is shown in Figure 4.

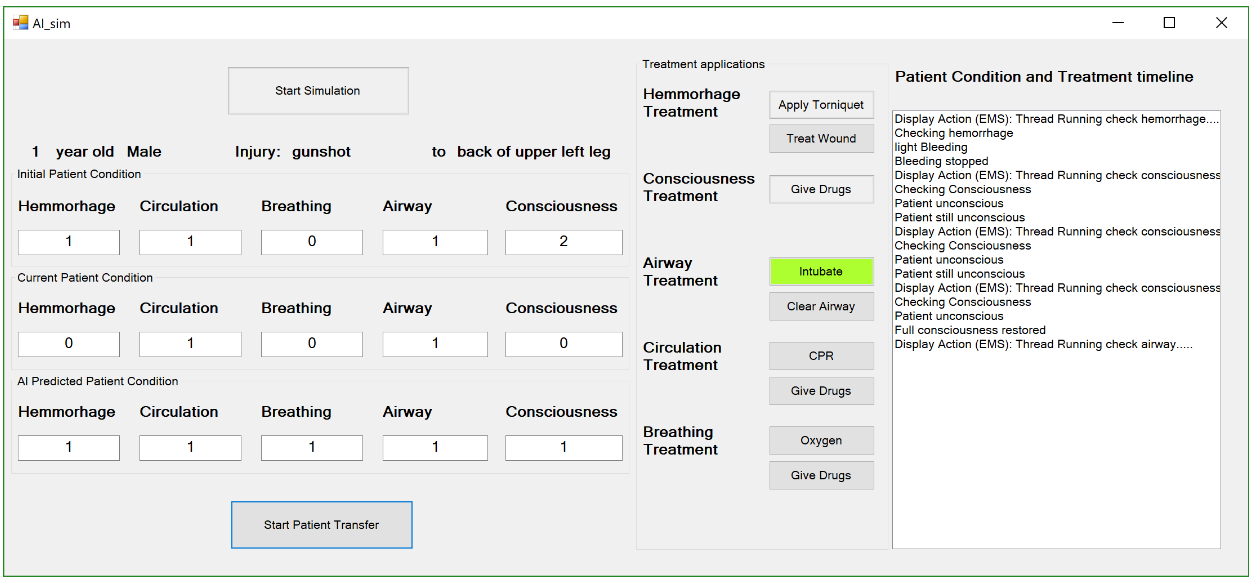
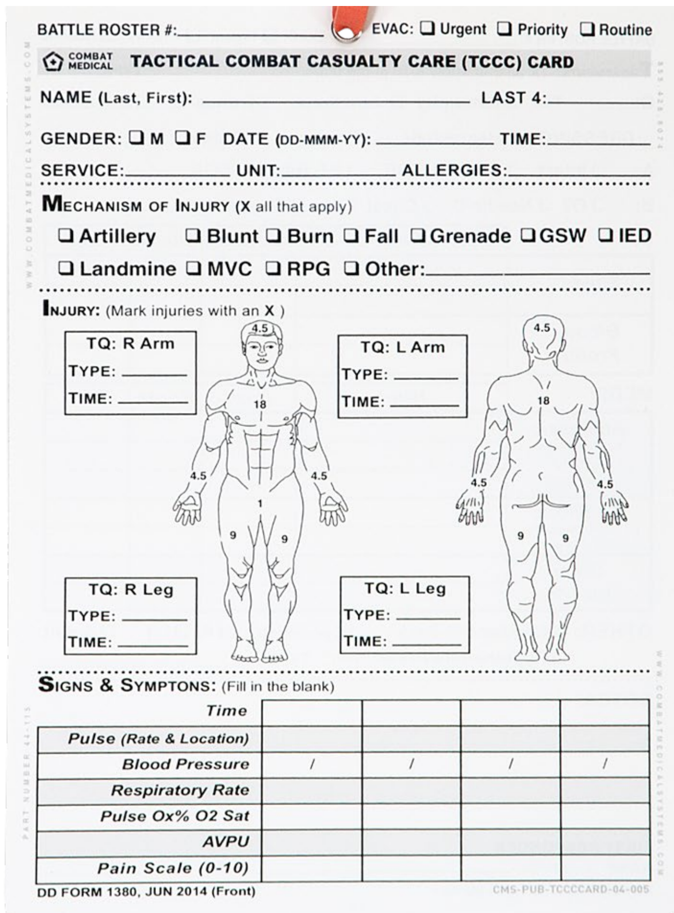


Figure 4. Scenario Generation Interface

The interface indicates the initial, current, and predicted patient status on a scale of 0 to 2, with 0 indicating no problem, 1 indicating a minor problem, and 2 indicating a severe problem or lack of function. This is a simple literal description of the underlying patient state within the model.

The participants will then conduct the information transfer phase. This phase will require the participants to input information from the pre-transfer phase into a standardized data-input form to be used in performance assessment. The information entry form used in the Transfer of Care simulation is based on Tactical Combat Casualty Care (TCCC) cards. The TCCC card is a standardized Transfer of Care procedure tool used by the military in medical evacuation (Medevac). The TCCC card is shown in Figure 5 and the corresponding simulation input form is shown in Figure 6.



BATTLE ROSTER #:__________ EVAC: ❑ Urgent ❑ Priority ❑ Routine

COMBAT MEDICAL TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

NAME (Last, First): __________ LAST 4:__________

GENDER: ❑ M ❑ F DATE (DD-MMM-YY): __________ TIME:__________

SERVICE:__________ UNIT:__________ ALLERGIES:__________

MECHANISM OF INJURY (X all that apply)

❑ Artillery ❑ Blunt ❑ Burn ❑ Fall ❑ Grenade ❑ GSW ❑ IED

❑ Landmine ❑ MVC ❑ RPG ❑ Other:__________

INJURY: (Mark injuries with an X)

TQ: R Arm TYPE: ______ TIME: ______

TQ: L Arm TYPE: ______ TIME: ______

TQ: R Leg TYPE: ______ TIME: ______

TQ: L Leg TYPE: ______ TIME: ______

4.5 18 4.5 4.5 1 9 9 4.5 18 4.5 4.5 9 9

SIGNS & SYMPTONS: (Fill in the blank)

Time				
Pulse (Rate & Location)				
Blood Pressure	/	/	/	/
Respiratory Rate				
Pulse Ox% O2 Sat				
AVPU				
Pain Scale (0-10)				

DD FORM 1380, JUN 2014 (Front) CMS-PUB-TCCCARD-04-005

Figure 5. Existing TCCC Card (DoD, 2014).

This provides an outline for the layout and type of information required in Transfer of Care but is specific to military patient handoff, containing mechanisms of injury such as "grenade" and "IED." To broaden the application of the simulator, the scenario generation and associated input form should be made more generic. As Transfer of Care is a dynamic, two-way interaction between trained professionals, (Example: *Standard Operating Procedure (SOP) for Patient Handoff Between a Healthcare Facility and a*

Transporting Ambulance, 2016). assessment of the performance of an individual in the training case, or of the ability of a training simulation to improve Transfer of Care from the perspective of an EMS professional is difficult to quantify. To enable quantitative assessment of either metric, the simulator was designed for participation by a single EMS professional. To minimize data-entry errors outside the scope of this study, a standard multiple-choice style form was utilized for both test scenarios. In the case of the AI-assisted version of the simulation, prompts and warnings were used to help the participant ensure data entry was complete and in-line with predictions of patient condition made within the AI.

This approach minimizes the difficulty in interpretation of variable inputs among participants and minimizes the bias in misunderstanding of specific inputs made by different subject populations, such as military and civilian. All the Transfer of Care information responses will be kept the same between the AI and non-AI-based simulations to minimize systematic bias in the experiment. The information transfer form from the simulator is shown in Figure 6.

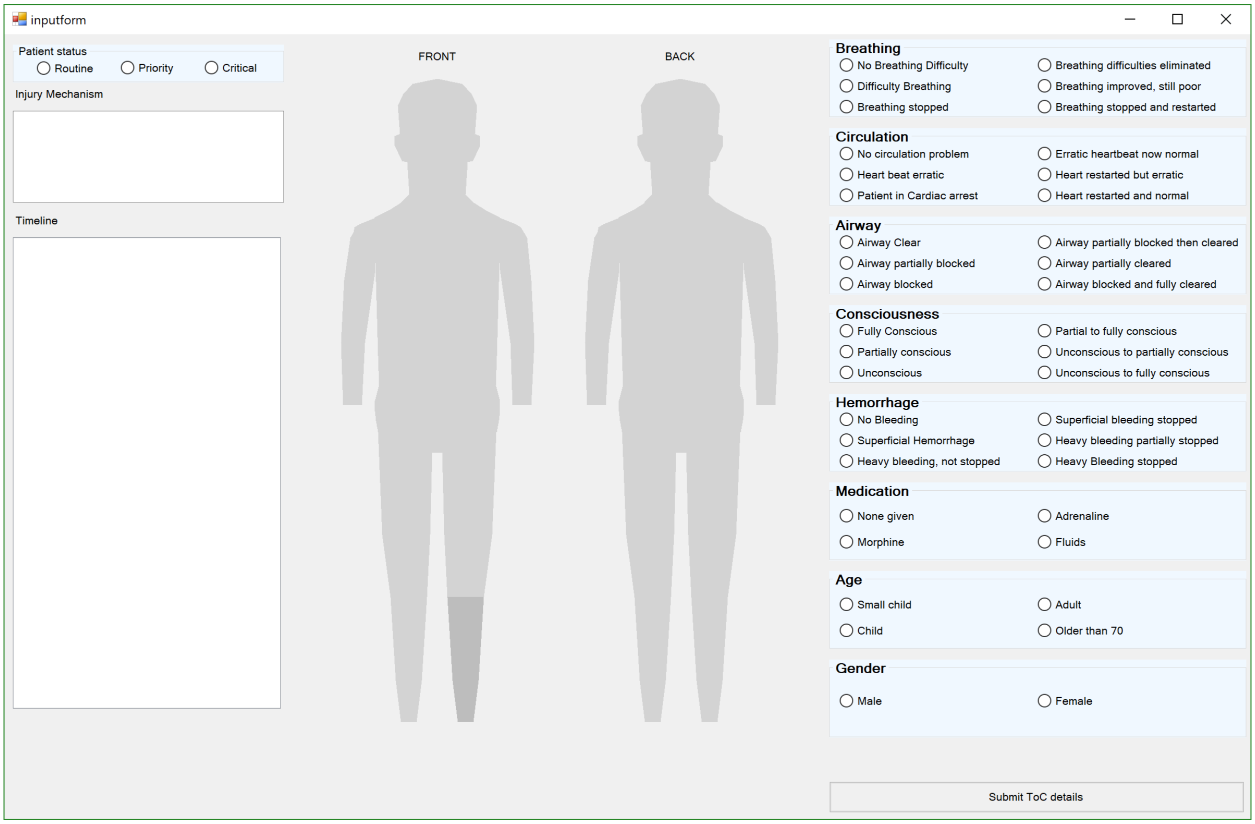


Figure 6. Patient Information Transfer Form

The form provides a visual feedback analog of the talkback protocol identified in the HTA. The layout of the form also reflects the existing paper-based Transfer of Care forms used by some healthcare agencies for emergency patient handoff. While these are not ubiquitous or standard, this design is at least a robust and credible starting point in developing an evidence-based Transfer of Care interface design. To enable the transfer of information, the simulation needed to include an information capture form. This interface was designed as a multiple-choice data entry form. Although this approach is not ideal, as it was not representative of the actual form, it made assessment possible and allowed for standardization of the transfer process within the simulation.

The Agent-Based model contains two primary agents—Patient and EMS (care provision agent) and two secondary agents—Triage (receiving agent) and the AI assistant—to allow realistic assessment of the ToC. The primary agents interact to develop a realistic EMS scenario to be observed by the training participant, the AI agent provides ToC-based advice in the AI version of the simulation, and the triage agent provides dynamic assessment of the Transfer of Care process within the simulation. These agents were integrated into a simulation of a complex emergency situation for participants to observe and attempt to pass accurate information back into the simulation with and without the AI assistant. The initial model contains only single instances of each agent with patient, and EMS agents contain both stochastic and deterministic behaviors derived from real-world datasets and standard operating procedures. The simulation generates a patient state that develops according to the intrinsic rules within the patient agent and automatic interventions determined by the EMS agent but actioned by simple confirmation by the training participant. This in turn generates unique data for each scenario to be re-entered into the simulation by the participant as accurately as possible.

3.2.6. Trainee Performance Assessment

After completion of the standardized Transfer of Care form, the patient state according to the simulation participant is "transferred" and compared to the baseline patient agent status developed in the simulation based on predetermined weighted scores for each patient characteristic and assessed for accuracy and completeness. While it is relatively easy to compare the information submitted to the patient baseline, doing so without careful consideration of the nature of each specific piece of information may result in unexpected bias within the simulation. As such, it was important to define assessment protocols that appropriately weighted both the accuracy and completion of the information given. The initial, low-fidelity simulator did not include these elements, but they were considered to ensure requirements were included in the final model.

4. Initial Design Review and Analysis

A heuristic evaluation of the initial design was conducted with SMEs from the WSU NCMR, Dayton, Ohio. In addition to the formal heuristic evaluation, the simulation was developed and tested throughout the production using the RITE method due to the requirement for an agile and time critical development path with a limited evaluation population as described by Medlock et al. (2002). A single SME from the WSU NCMR was asked to assess the simulation at biweekly intervals to progress the simulation development. The application of the RITE method allowed verification of modifications to be made quickly and expedite the design and development phase. As this is only an evaluation of the initial design, full results are not presented. This section details the significant findings of the review. The mitigations designed to resolve each aspect of the simulator that required attention are detailed in the final prototype design section, the difference between the initial and final design is an implicit representation of this process. Significant elements that were removed from the design are also highlighted here. After the heuristic evaluation of the initial simulation, a full design analysis was conducted to establish the enhancements and mitigations to the issues identified. The results of this analysis are presented in line with the design review findings. As defined by the RITE method, the implementation and retest of these design elements was conducted as each modification was made, rather than waiting for a new test release of software.

4.1. Model Elements

4.1.1. Patient Degradation

The initial simulator did not have any patient degradation modeling included. This contributed to unrealistic scenario development and a lack of variability in the output. Therefore, an additional patient degradation model needed to be included into the patient agent.

4.1.2. EMS Treatment Hierarchy

The initial implementation of the prioritization of treatments was not felt to be complete or accurate. This resulted in confusing treatment actions being presented to the user. This needs to be representative of the decisions and treatment options that would be made by a real EMS professional. Hierarchy and prioritization rules should be redesigned to ensure all outcomes and combinations of conditions are included.

4.1.3. EMS Degradation Checking Logic

The initial model did not contain any patient degradation modeling. Once this is included, modifications to the EMS agent logic are required. An additional "check degradation" function is needed to support the EMS agent to support this patient function.

4.2. UI Elements

4.2.1. Voice Assistant

The initial simulation utilized a voice-activated AI assistant for information input and treatment actioning tasks. During evaluation, it was found that this was not reliable enough to use in the prototype application. This implementation resulted in repeated attempts to action commands and extra delays in both the Scenario Generation and Information Transfer phases. Therefore, the voice assistant should be removed until a more robust and reliable solution can be implemented.

4.2.2. Patient Characteristics Display Not Intuitive

The existing implementation describing patient characteristic states on a scale of 0 to 1 is not intuitive and does not give an indication of how good or bad the condition is. A rising scale indication with appropriate color coding and bounding of the possibility of patient condition for degradation or improvement should be implemented.

4.2.3. Patient Predicted Condition Display

As with the patient characteristics, the prediction of future characteristics is not intuitive or informative, especially without explanation of the output. The design should incorporate a rising scale indication with color coding and intuitive indication of change of state probability.

4.2.4. Use of Windows Standard Theme

Although this scheme is well known, it was not considered an inspiring or interesting design choice and was associated with applications that are potentially outdated or simplistic. A more up-to-date UI theme should be implemented, taking note of the choice of appropriate colors and fonts for the use as a medical training simulation.

4.2.5. Freeform Text Entry

The freeform text entry box for injury-type can result in erroneous entry of this aspect of the Transfer of Care information. The freeform box should therefore be changed to a dropdown box style data input. This could include a freeform option in a real-world implementation where precise description of the injury for interpretation by a human is more important than being able to easily assess and compare the input value to a "true state" value in the patient agent.

4.2.6. Information transfer input elements

The input elements are distributed across the screen and could lead to incomplete data entry. –

These should be consolidated into a single area, on the right of the screen to reinforce the positioning of action buttons across the revised UI. This reinforces consistency and users cognitive models, simplifying the simulator UI.

4.3. Data Requirement

4.3.1. NEMSIS Database limitations

To ensure realism, the AI that feeds the improved decision-making process will be built on real data and utilize machine learning to maintain and improve the underpinning data and assumptions. The NEMSIS database, (Mann, 2016), maintained by the University of Utah, collates detailed information on EMS events throughout the United States. This database contains information from over 40 million real-world EMS events, detailing timelines of injury, treatment, and outcome in each case on injury classification, patient age, treatments or procedures performed, time of incident, and time of arrival at the Transfer of Care location. The full publicly available subset of data covers around 2 million incidents. The data set was split into training and test sets, each with 1 million samples. This was due to the small number of deaths collated in the 250,000 samples used in the initial design synthesis. This four-fold increase in samples was intended to take the total number of deaths considered in the simulator to over 100. These data were converted into representative statistical distributions of each information stream to enable mathematical generation of representative data within the model rather than requiring the AI to contain such large datasets.

While this diminishes the fidelity of the event-specific information, it provides a simple and relatively small set of variables which govern patient condition development and can be easily modified by data generated in the simulation. In addition to this, specific data on how patient vital signs affect each other were used to implement patient condition development. These datasets were used to determine transition probability and set of actions. Depending on the distribution of real data, the agent’s behavior changes.

In addition to the NEMSIS data, secondary sources of injury probability distribution were used to inform the statistical representations of the simulation models. Where either the NEMSIS database or alternative sources were used to define probability distributions, the relevant source is detailed in the rules and quantification of the models.

5. Simulator Prototype Design Detail

A prototype Transfer of Care simulator was built in C# using the Microsoft Visual Studio development environment. As detailed previously, the Agent-Based model contained two primary agents—Patient and EMS (care provision agent)—and two secondary agents—Triage (receiving agent), and the AI assistant to allow realistic assessment of the ToC. The primary agents interact to develop a realistic EMS scenario to be observed by the training participant, the AI agent provides Transfer of Care-based advice in the AI version of the simulation, and the triage agent provides dynamic assessment of the Transfer of Care process within the simulation. These agents were integrated into a simulator to present a complex emergency situation for participants to observe and attempt to pass accurate information back into the simulation with and without an AI assistant. The initial model contains only single instances of each agent, with patient and EMS agents containing both stochastic and deterministic behaviors derived from real-world datasets and standard operating procedures. The simulation generates a patient state that develops according to the intrinsic rules within the patient agent and automatic interventions determined by the EMS agent but actioned by simple confirmation by the training participant. This in turn generates unique data for each scenario to be re-entered into the simulation by the participant as accurately as possible.

5.1. Architecture

The simulation architecture was developed using a model-view-controller architecture pattern across all three phases of the simulation. The architecture and the associated flow of data, information inputs, and actions are shown in Figure 7. In this representation, data is information within the model, transferred either between the View and Model layers or between agents in the model layer. Once data reaches the view layer, the graphical representation classifies data as information to the user. The controller layer in the simulation is a keyboard for this model; however, AI voice assistant control elements were initially considered, and could be considered, to automate elements of the controller-model relationship. The model layer contains the three agent elements of the simulation—Patient, EMS, and AI/Simulation intelligence. This specifics of each of these agents are detailed in the following sections, but from an architecture perspective, it is important to note that they are independent agents with behaviors and memory. Data are generated and passed to the view layer for presentation to the user. The model layer remains consistent throughout all three phases of the simulation. There is no modification to the behaviors, although patient and internal procedure data remains fixed after the second phase. This is primarily to ensure a consistent baseline for Transfer of Care assessment within the model. In a real-world scenario, there could be development of the patient condition during the Transfer of Care period; but in this case, it is assumed to be static. The View-Model Layer, while not explicit in the figure, is a more explicitly defined version of the controller layer.

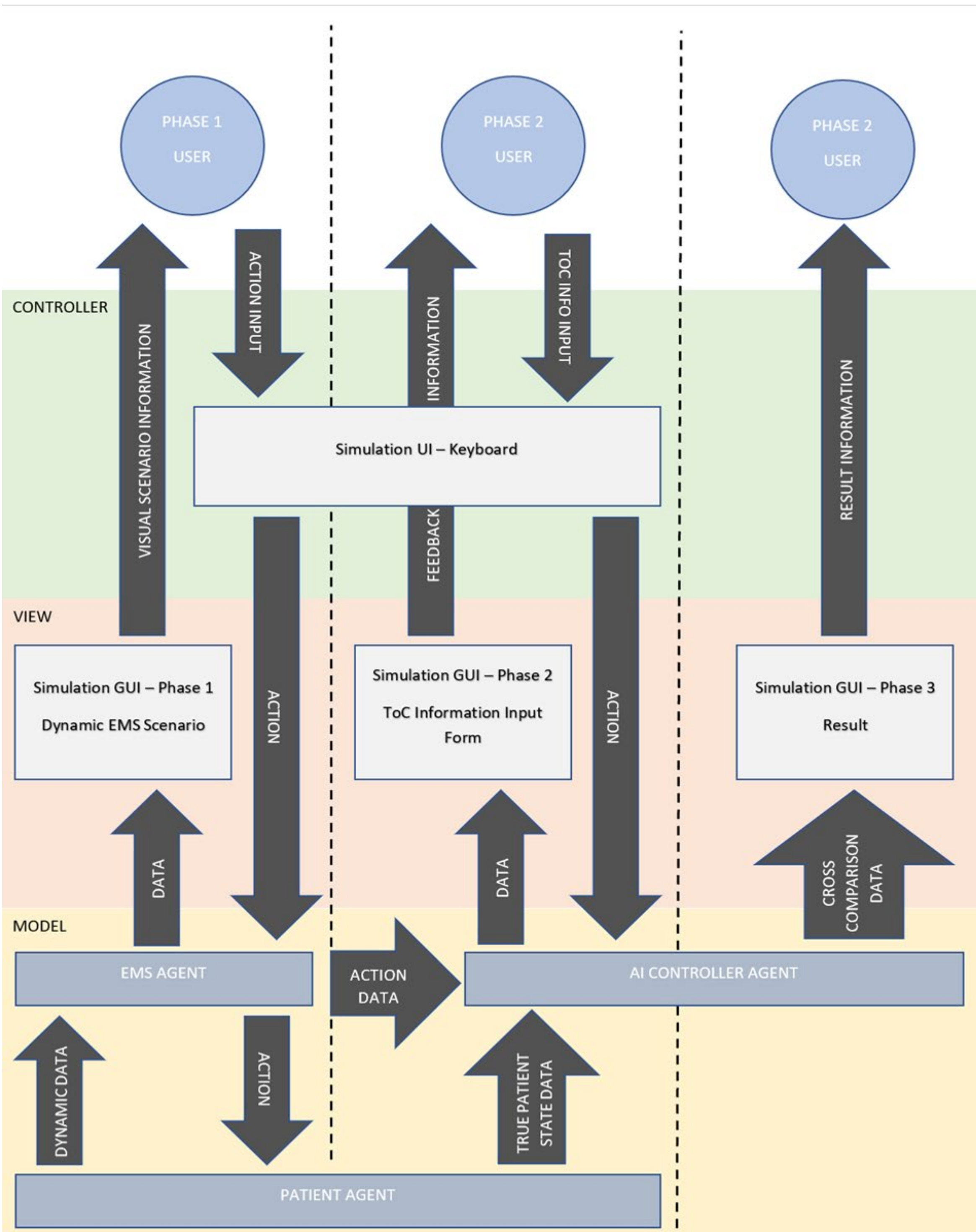


Figure 7. Simulator Architecture Overview

Within the overall architecture, the configuration of the top-level simulation components within the model layer and their connections is shown in Figure 8.

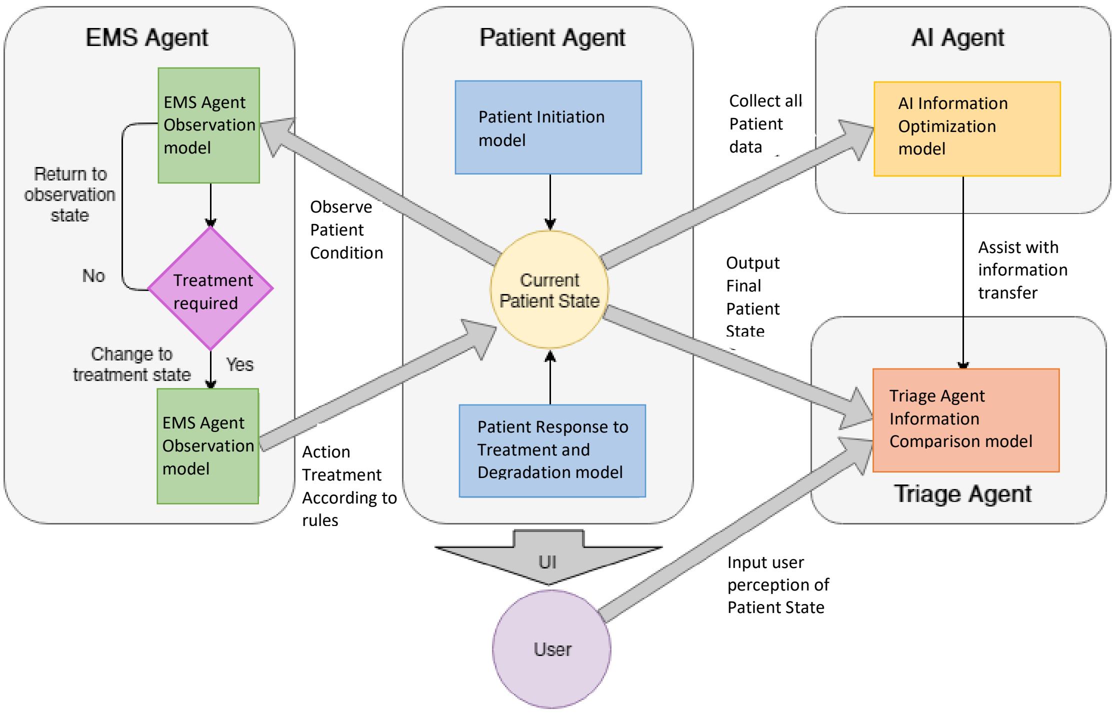


Figure 8. Simulator Configuration Overview

5.2. Design Definitions

The following sections provide definitions for the elements used with the models that make up the Transfer of Care simulator.

5.2.1. Environment

The "Environment" in this project is the virtual space where interactions between the two agents take place. It is a collection of events and connections from which the respective agents will learn and take actions. The environment itself does not have rules that influence the simulation but provides the structure for the model to develop.

5.2.2. Policy

The term "Policy" refers to a rule of the simulation under which agents work or interact with each other to achieve the optimal reward value. The EMS team also has worked under certain policies; for example, the team will be provided with a fixed set of actions for a specific treatment to achieve the maximum reward. For example, for treating hemorrhage, the EMS team can either apply tourniquets or just provide medication to alleviate pain. The action will determine the reward allocated within the simulation, and every action under the process is bounded by policy.

5.2.3. Action

In the development of this simulation, an "Action" is the procedure taken by the virtual or human paramedic team performing the treatment—for instance, applying a tourniquet, providing specific treatments, or clearing the airway. Every set of actions leads to different impacts on the patient agent and increased complexity in the simulation.

5.2.4. States

In the Agent-Based Simulation model, "States" refers to the patient health state. The three possible states that the patient can be in are Good, Fair, and Critical. The state can be further broken down into the state of different health metrics such as level of hemorrhage, airway status, consciousness level, etc. Improving those individual health variable metrics results in increment of rewards.

5.3. Patient Agent

The patient agent is initiated with several fixed variables defining the patient and their injury type. These are fixed as the simulation starts and do not change; see Table 8. In addition to this, there are dynamic patient characteristics for Circulation (heart function), Hemorrhage (bleeding), Breathing, Airways, and consciousness on a three-point scale from 0 to 2, with 0 being no problem in the characteristic, 1 being minor problems, and 2 being serious complications; see Table 9. These initial fixed and dynamic characteristics or variables are assigned based on initial injury distributions derived from the NEMSIS database and develop throughout the simulation. The final patient state is dependent on the interaction with the EMS agent and the treatments applied as well as degradation rules that are implicit within the patient agent and also based on data from the NEMSIS database and alternative, non-quantitative sources where this was not exhaustive or granular enough. The use of the partially observable model in this case is representative of the fact that the patient condition will vary depending on the success of the EMS agent intervention, which is a stochastic interaction with different potential outputs depending on the time of the intervention. The patient agent is continuously updating its “state” throughout the simulation and providing feedback to the trainee as Good, Poor, or Critical based on the state of different health metrics as defined in Table 8. The change in the state of the patient agent is governed by its intrinsic stochastic modeling agent and the policies associated with the EMS and patient interaction.

Table 8. Fixed Variables

Characteristic	Levels
Age	Small Child (1–3) Child (4–17) Adult (18–69) 70-plus (70+)
Gender	Female Male
Injury Type	Gunshot
Injury Location	Front Head Front Torso Front Midsection Front Upper Arm Left Front Upper Arm Right Front Lower Arm Left Front Lower Arm Right Front Upper Leg Left Front Upper Leg Right Front Lower Leg Left Front Lower Leg Right Back Head Back Torso Back Midsection Back Upper Arm Left Back Upper Arm Right Back Lower Arm Left Back Lower Arm Right Back Upper Leg Left Back Upper Leg Right Back Lower Leg Left Back Lower Leg Right

Table 9. Dynamic variables.

Characteristic		Levels
Hemorrhage		0 – No bleeding 1 – Light bleeding, treatable with Sucher or simple dressing 2 – Heavy bleeding – requiring tourniquet, etc.
Circulation		0 – No heart issue 1 – Palpitations, tachycardia, or bradycardia 2 – Heart attack
Breathing		0 – No breathing difficulty 1 – Some breathing difficulties, shortness of breath, or wheezing 2 – Stopped breathing
Airway		0 – No blockage 1 – Partial blockage to airway 2 – Airway completely blocked
Consciousness		0 – Patient fully conscious 1 – Patient partially unresponsive 2 – Patient unconscious

As well as defining the initial injury, the simulation will define initialization parameters for all these characteristics. For different injury types, some of these characteristics will be primary drivers; for instance, in the case of a gunshot injury, hemorrhage level is a primary driver variable, but the other characteristics will be influenced by the level at which the hemorrhage is defined. These will be based on real-world relationships where possible.

There are two levels of dynamic variables within the simulator, which, as well as representing critical and non-critical injuries, also have specific additional rules with the simulation that are specific to the connections within the agent. Level 2, or critical injury, characteristics are those that allow other dynamic characteristics to be impacted by the simulation depending on underlying stochastic rules. It is possible for the simulation to degrade certain characteristics initialized at zero if appropriate conditions are met; e.g., if a patient has a minor, level 1 hemorrhage, it can degrade to a level 2—heavy bleeding—and in turn cause the patient to lose consciousness and potentially have a circulation or heart problem. Only when a patient characteristic is critical can other variables be impacted by this state. Figures 9 and 10 describe the design of the patient agent elements. Figure 9 gives an overview of the patient agent, showing the connections between the states, behaviors, and external inputs. The initialization subgroup is activated only when the simulation starts and runs only once. Figure 10 details how the patient variables or states can interact with each other. These are the rule-based logical definitions that underpin the simulation, but the timings of each of these treatments are also an aspect of the simulation, enabling only a defined number of treatments in the fixed simulation duration. The actual duration of the treatments is defined on estimates of actual timings of treatments defined in RLVC Requirements Document (2016), scaled by the same factor as the overall simulation. The timings are detailed in Table 10.

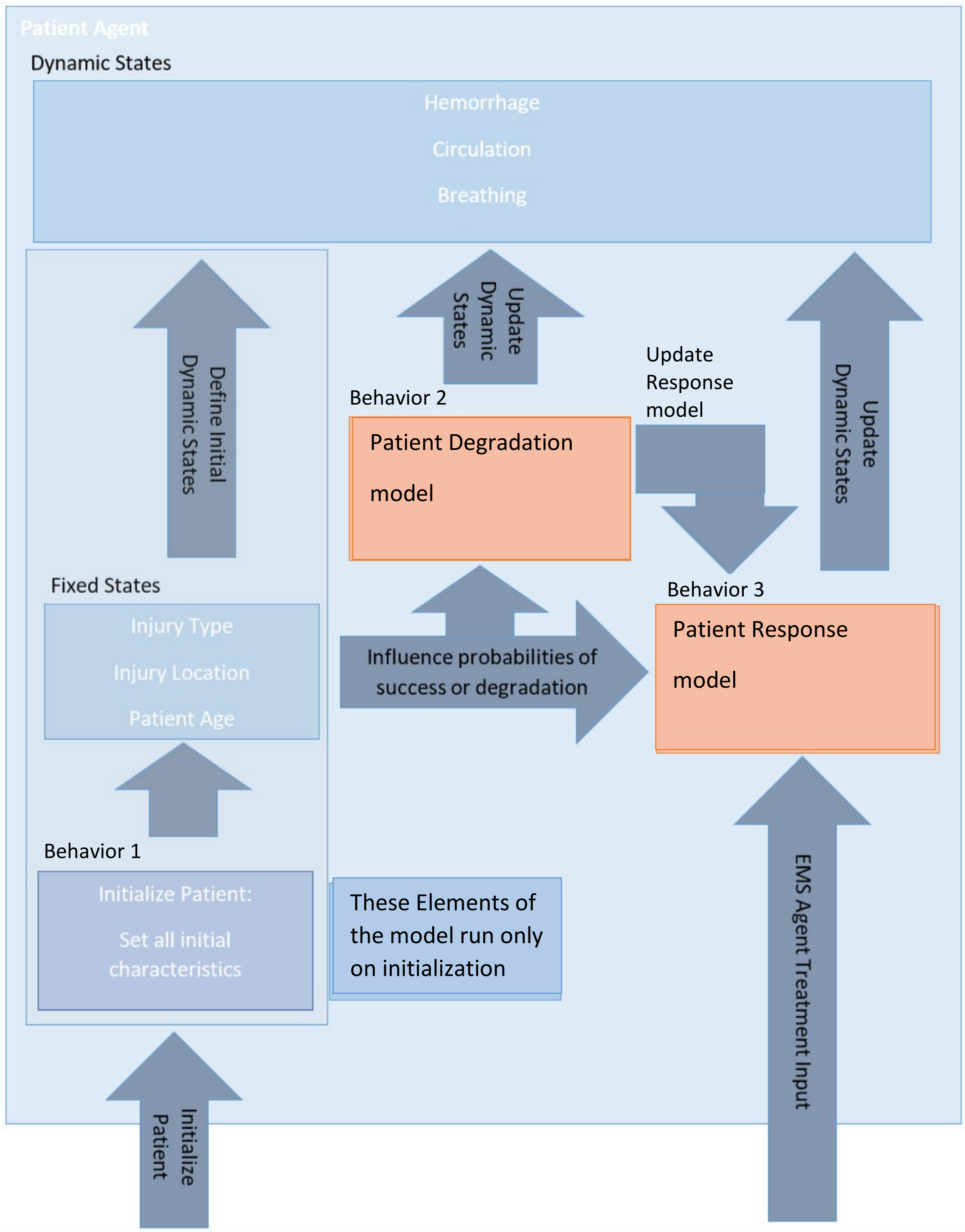


Figure 9. Diagram of Patient Agent—States, Behaviors, and Connections

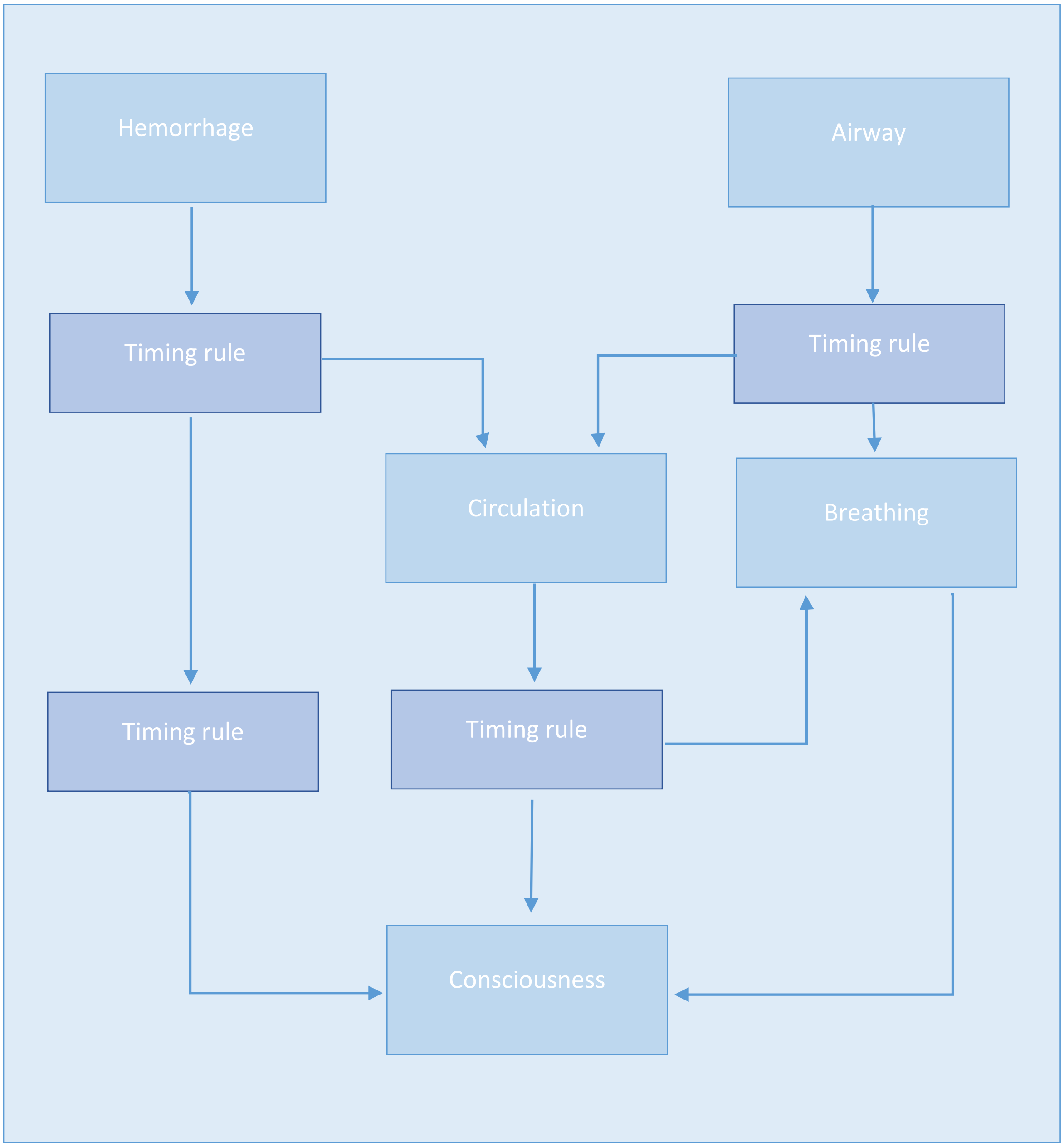


Figure 10. Diagram of Patient Agent—States, Behaviors, and Connections

Table 10. Treatment Timings, Success Probability, and Success Probability Delta Functions

Treatment	Time (m)	Initial Success Probability (%)	Probability Change (%)	Source
Airway—Intubation	2	85	+5 −5	Timings—RLVC Requirements Document (2016) Ahmed et al. (2017). Probability changes are assumed
Airway—clearing	1	60		Timings—RLVC Requirements Document (2016) Ahmed et al. (2017). Probability changes are assumed.
Consciousness treatment	2	50 (for any positive change of state)	+5 if no critical −5 if critical	All based on assumptions by the author.
CPR (heart only or heart-breathing)	5	15 (10 partial, 5 full)	0 −5	Timings—RLVC Requirements Document (2016) Probabilities—Carr (2016) Probability changes are assumed.
Tourniquet application (heavy bleeding)	2	60	0 −10	Timings—RLVC Requirements Document (2016) Probability changes are assumed.
Hemorrhage treatment (light bleeding)	2	90	0 −5	Timings—RLVC Requirements Document (2016) Kragh et al. (2008).
Heart arrythmia	2	30	0 −5	Timings—RLVC Requirements Document (2016) Probabilities—(Carr, 2016) Probability changes are assumed.
Irregular breathing	2	40	0 −5	Timings—RLVC Requirements Document (2016) Probabilities—(Carr, 2016) Probability changes are assumed.

5.4. EMS Agent

The purpose of the EMS agent is to provide independent interventions from the patient model that represent the potential actions of EMS in a real-world emergency without the need for the simulation participant to provide detailed intervention instructions. This is to ensure that the focus of the simulation is the transfer of care information rather than the provision of the care. The EMS agent interrogates the patient agent and provides rule-based interventions, with probability of success dependent on the patient characteristics, injury severity, number of previous attempts, and time since injury. In the case of multiple injuries, only a single intervention can be actioned by the agent at a given time. The interventions are based on SME expertise and probability of success derived from the NEMSIS database. The simulation will require the participant to acknowledge each action, whether successful or not, so that they develop an overall picture of the patient conditions and interventions prior to the information transfer phase. The patient agent component has two behaviors—analysis of the patient agent for change of condition and providing treatment to the patient agent, and two states—non-receptive and receptive. The EMS agent also stores a version of the patient agent states that is updated only if the EMS agent applies treatment or checks the patient condition. The overarching logic of these behaviors and states is described in Figure 11. The patient condition behavior logic is outlined in Figure 12, and the treatment behavior logic is shown in Figure 13. The probability of success of treatment and associated variability depending on treatment success are defined in Table 10. While these are dependent on the action of the EMS agent, they are intrinsic to the patient agent. A key function of the EMS agent is to prioritize and suggest optimal treatment strategies so that the trainee does not have to consider this and can focus on the Transfer of Care learning. The prioritization hierarchy used in the simulator is detailed in Table 11. This is almost always a simple hierarchy, with each treatment being applied if those above it in the hierarchy are not needed or are successful. The exception to this is when the patient has critical circulation and bleeding characteristics, in which case the treatment priority is iterative between these two, until one or both are successful. As such, they are denoted 1a and 1b in the hierarchy.

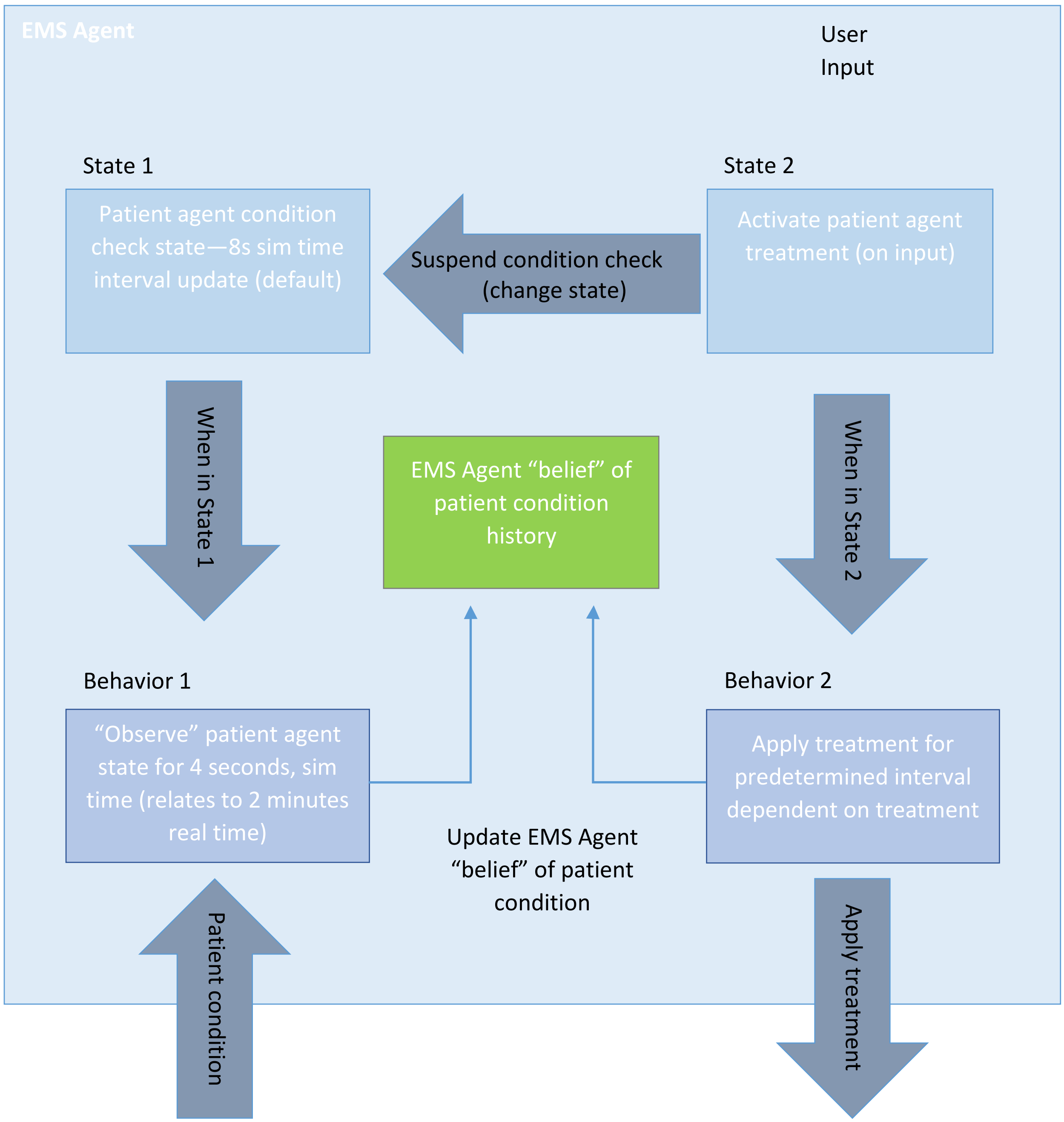


Figure 11. EMS Agent Overview

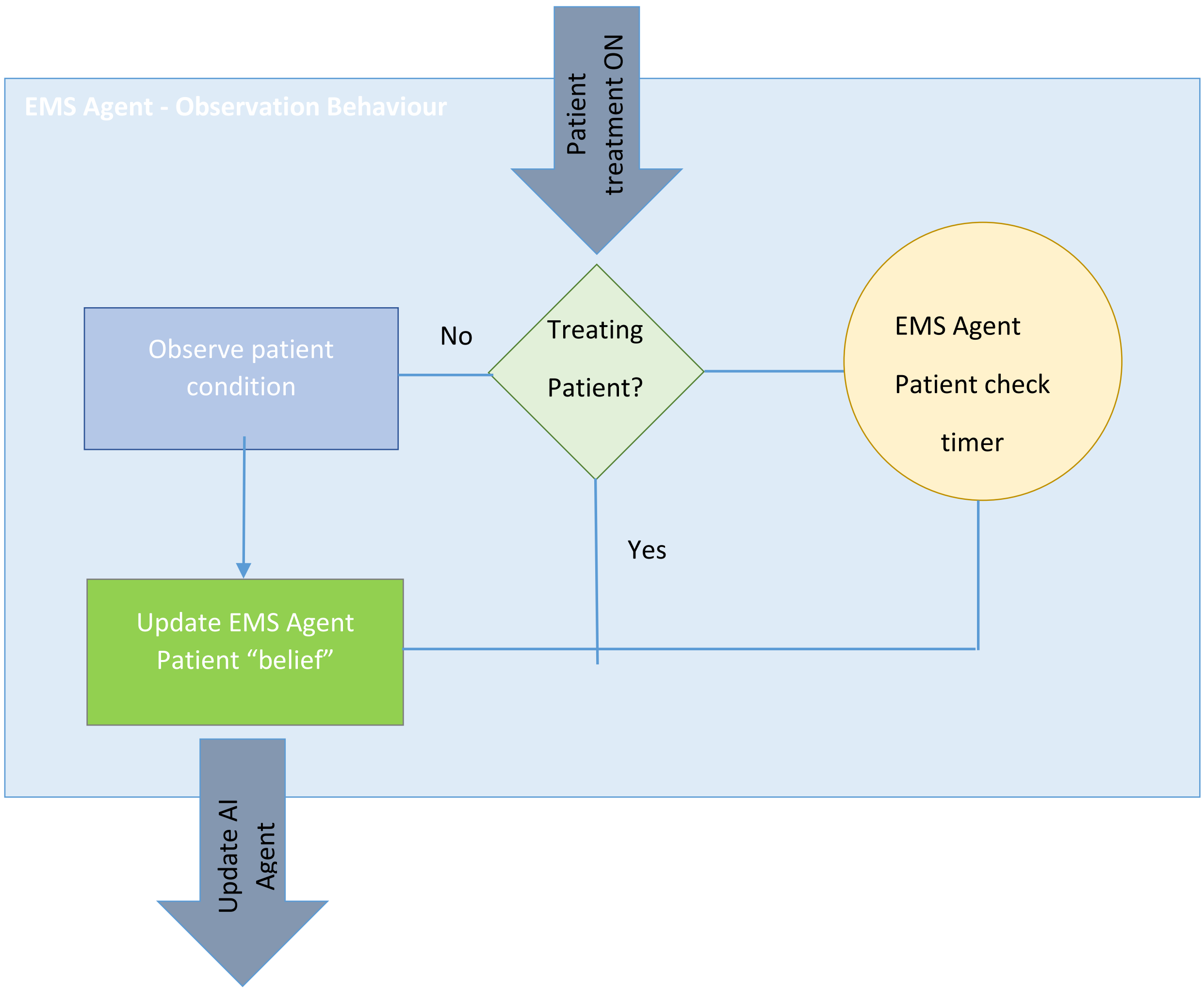


Figure 12. EMS Agent Observation Behavioral Logic

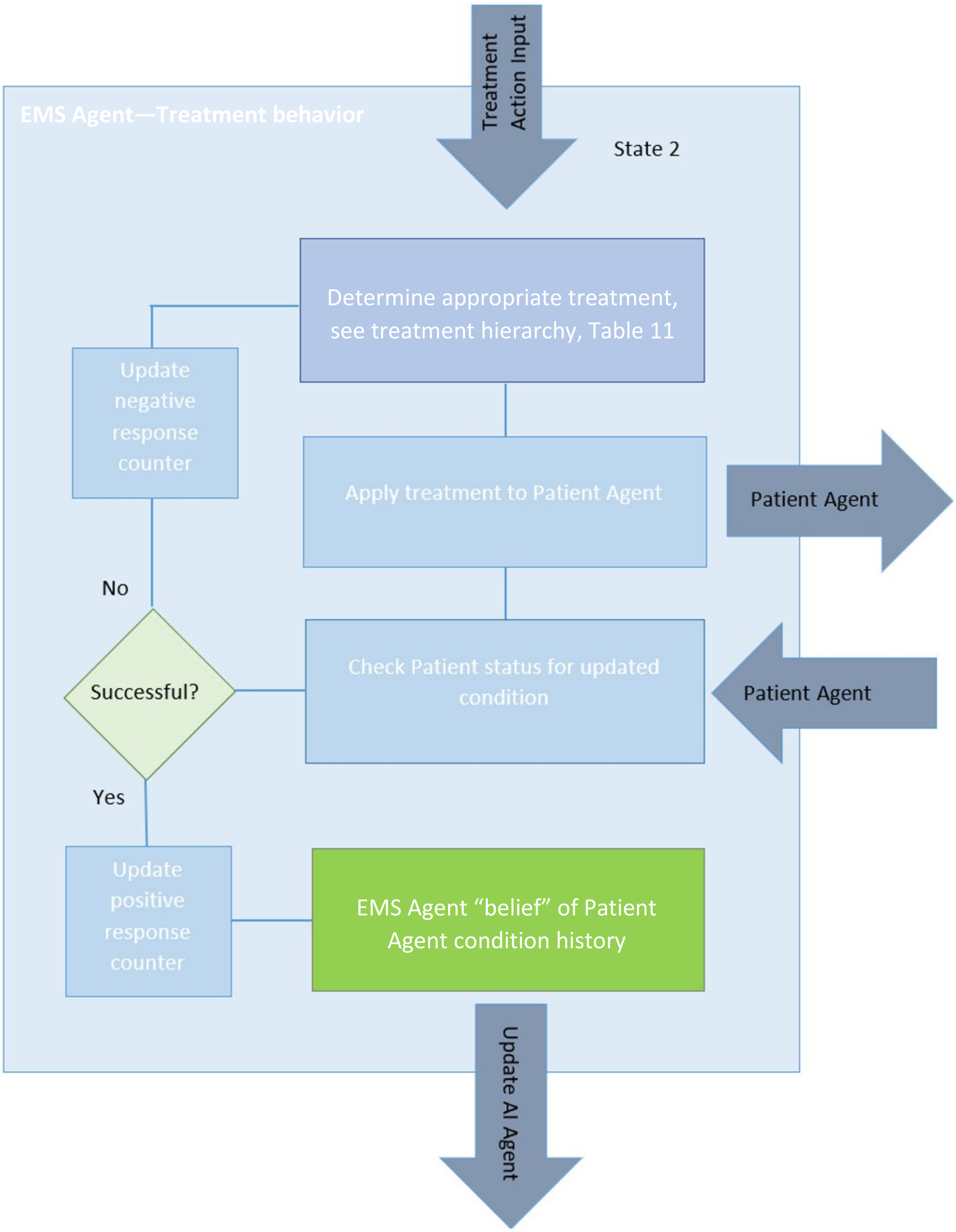


Figure 13. EMS Agent Treatment Behavioral Logic

Table 11. Treatment Prioritization Hierarchy

Order	Treatment of Symptom	Dependencies
1a	Treat critical circulation	• If circulation is critical, attempt first. • If attempted more than once, attempt 1a. • If attempted more than three times, change from CPR approach to defibrillation.
1b	Treat critical bleeding	• If circulation not critical attempt 1a. • After each attempt, return to 1a if circulation still critical. • Repeat iteration until six iterations
2	Treat critical airway	• If circulation and bleeding not critical attempt 2. • If unsuccessful twice attempt intubation
3	Treat critical breathing	• If circulation, breathing and airway not critical, attempt 3.
4	Treat critical consciousness	• If no other characteristic is critical, attempt to revive unconscious patient.
5	Treat non-critical circulation	• If no patient characteristics are critical, attempt 5.
6	Treat non-critical bleeding	• If no patient characteristics are critical and patient has no heart problem, attempt 6.
7	Treat non-critical airway	• If no patient characteristics are critical and patient has no heart problem or bleeding, attempt 7.
8	Treat non-critical breathing	• If no patient characteristics are critical and patient has no heart problem, bleeding, or airway problem, attempt 8.
9	Treat non-critical consciousness	• If patient has no other problem, attempt 9.

5.5. AI Agent

The simulation provided both a standard and an AI-assisted scenario to assess the impact of AI. The AI provided two types of assistance to the training participant. First, the AI agent utilized the MDP model to predict any likely changes to patient condition based on probabilistic models derived from the NEMSIS data. It was hypothesized this would allow more accurate estimation of future patient condition and potentially reduce the workload in training participants, enabling greater situational awareness and more efficient information transfer. Second, the AI agent provided real-time assessment of the completeness and any potential conflicts or inconsistencies in the information submitted.

5.6. Triage Agent

The simulation contained a triage agent. As the prototype simulator was aimed at improving EMS performance, a triage agent was required to simulate those elements of the process that would typically be conducted by the receiving nurse at the primary care unit. There are typically two information transfer aspects involved in this role—collecting information and performing the talkback function described in section 2.1 as highlighted in the Task Analysis. In this simulator, this functionality is partially provided by the inclusion of multiple-choice data entry, which limits the mistakes that can be made by limiting the options available. In addition, the simulator provides audio feedback to confirm the data entry to the trainee, minimizing the chance of error. The simulator contains a data input page that approximates the data collection task of the triage professional. Once this data is collected, the information is assessed as part of the triage agent functionality. The rules defining this assessment are detailed in section 5.6.1.

5.6.1. Transfer of Care Assessment

As a training simulator, the system needs to be capable of measuring the success of the participant in meeting the goal of the simulation. Once the simulation has been run and the training participant has entered Transfer of Care information into the simulation, the information must be assessed for accuracy and completeness. While it is relatively easy to compare the information submitted to the patient baseline, doing so without careful consideration of the nature of each specific piece of information may result in unexpected bias within the simulation. As such, it was important to define assessment protocols that appropriately weighted both the accuracy and completion of the information given. This process was conducted in association with subject matter experts from the Wright State NCMR. The weights are detailed in Table 12.

Table 12. Information Score Weighting

Metric	**Weight**
(information metrics)	
Criticality	5
Circulation	5
Hemorrhage	5
Breathing	4
Airway	4
Consciousness	4
Injury type	3
Injury location	3
Age	2
Gender	1
(time metrics)	
Time to complete process	5

The scoring system used was a 1–5 scale for all metrics, the assignment of the score being based on the criteria described in Table 13 for the patient characteristics and Table 14 for the timings. The scoring of the patient characteristic input is based on the six possible states of information input in the simulator and the relationship to the "truth state" generated by the patient agent. This approach provides a consistent and simple scoring mechanism and a transparent information prioritization along with a more robust and informative score for the Transfer of Care simulator. The current scoring is linear and utilizes a ranking approach. This may not be the optimal solution as it potentially does not establish large enough deltas between correct and incorrect information transfer.

Table 13. Assessment Scoring Protocol (Characteristics)

Score	**Description**	**Criticality sum**
5	Correct information given	0
4	Minor problem over-specified as Critical	-1
3	No problem over-specified as Minor	2
2	No input or condition identified as Good when condition is Minor	1
1	Condition identified as Minor when real condition is Critical	0
0	No input or condition identified as Good when condition is Critical	-

Table 14. Assessment Scoring Protocol (Timings).

Score	Information	Time
5	Correct information given during Transfer of Care (e.g., Patient status 1: Transferred status 1)	Less than 2:00 minutes
4	Transferred status one stage higher than actual criticality (e.g., Patient status 1: Transferred status 2)	2:00 to 2:15
3	Transferred status two stage higher than actual criticality. (e.g., Patient status 0: Transferred status 2)	2:15 to 2:30
2	No status transferred	2:30 to 2:45
1	Transferred status one stage lower than actual criticality. (e.g., Patient status 2: Transferred status 1)	2:45 to 3:00
0	Transferred status one stage lower than actual criticality. (e.g., Patient status 2: Transferred status 0)	Over 3:00

Using this Agent-Based Simulation as a training system is expected to improve the information transfer process by improving decision-making and, in EMS professionals, by increasing exposure to complex Transfer of Care scenarios and providing immediate feedback on both successful aspects and areas for improvement. The parallel development of AI elements within the simulation will support the removal of unwanted, incorrect, and misleading information and improve the quality of data transfer in emergency situations, reducing EMS workload, and potentially could be adapted for use as an operational support tool. Successful application of this solution could provide an improved Transfer of Care process as part of the wider healthcare system and might reduce the workload in triage departments and improve patient outcomes by improving the quality and timeliness of information transfer in medical centers.

5.7. Final User Interface Design

There were several large refinements of the UI scheme and detail made to enhance the usability and utility of the simulator. The main structural and thematic changes are as follows:

- The theme of the simulator was changed from a standard Windows form design to a bespoke design with clearer, more modern design elements.
- The simulation was reduced from five to four screens—the initial "start" screen was removed and the simulation loaded directly into the intro form.
- Each phase of the simulation was made a standard shape with corresponding title bars and added screen progress indication.

The detailed UI enhancements are shown in Figures 14 to 24. The rationale for these design decisions is provided alongside each figure.

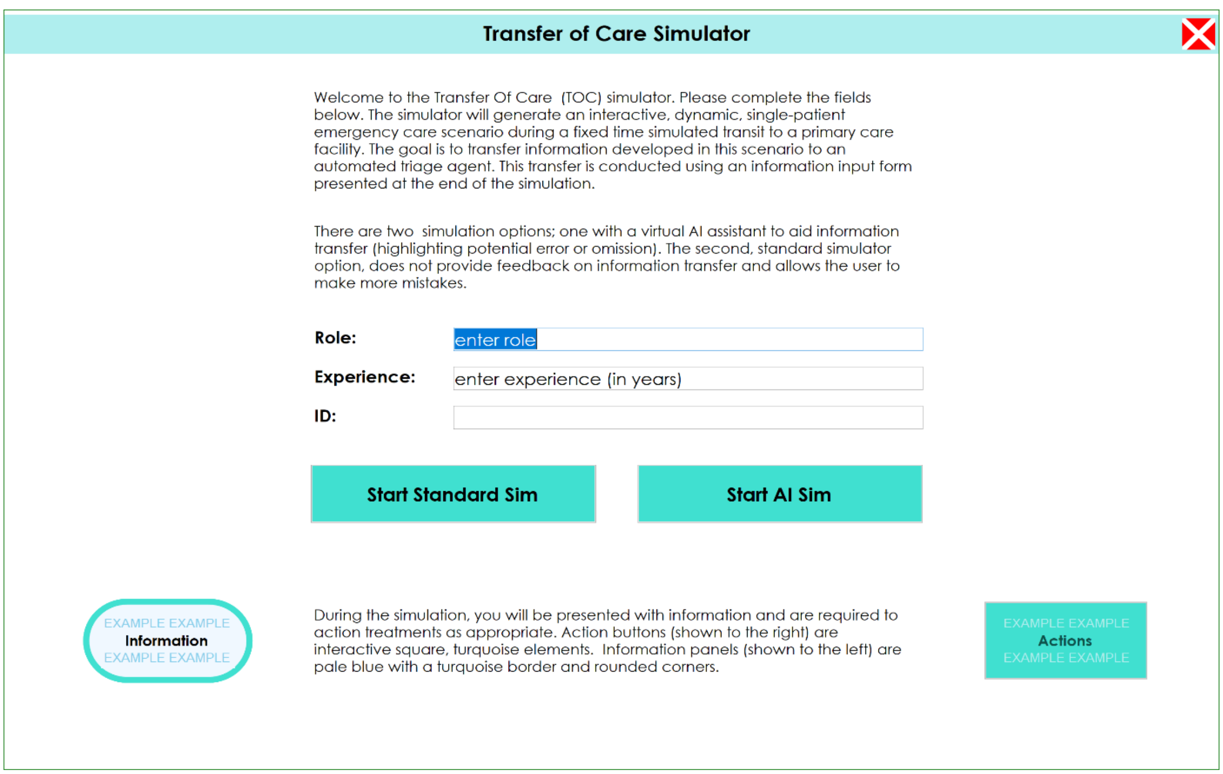


Figure 14. Introduction and Instruction Screen

The initial instructions on how to use the simulator were shown, during initial heuristic evaluation, to be somewhat unclear and to contain ambiguity. There was also no explanation of what to expect in terms of interactive elements of the simulator and passive messaging. The introductory paragraph was rewritten and split into two paragraphs, first, an explanation of the overall goal of the simulator, and second, the differences between the two options. An additional paragraph was added, including examples of interactive elements and messages to clarify the expectations of the UI. To eliminate confusion as to the purpose or functionality of these sample elements, they were labeled accordingly. The final introduction page, including these amendments, is shown in Figure 14. The classic Windows control bar was removed from all pages in the simulator and replaced with a box containing a white cross on a red background. This gave the UI a cleaner look while maintaining the user's expectations for the position and appearance of the "close application" facility. The inputs were designed with error checking for null or incorrect entries to ensure information was collected appropriately.

The aim of the information presented on this screen is to increase the learnability, and therefore the usability, of the simulator and to ensure it can be used without the oversight of an instructor.

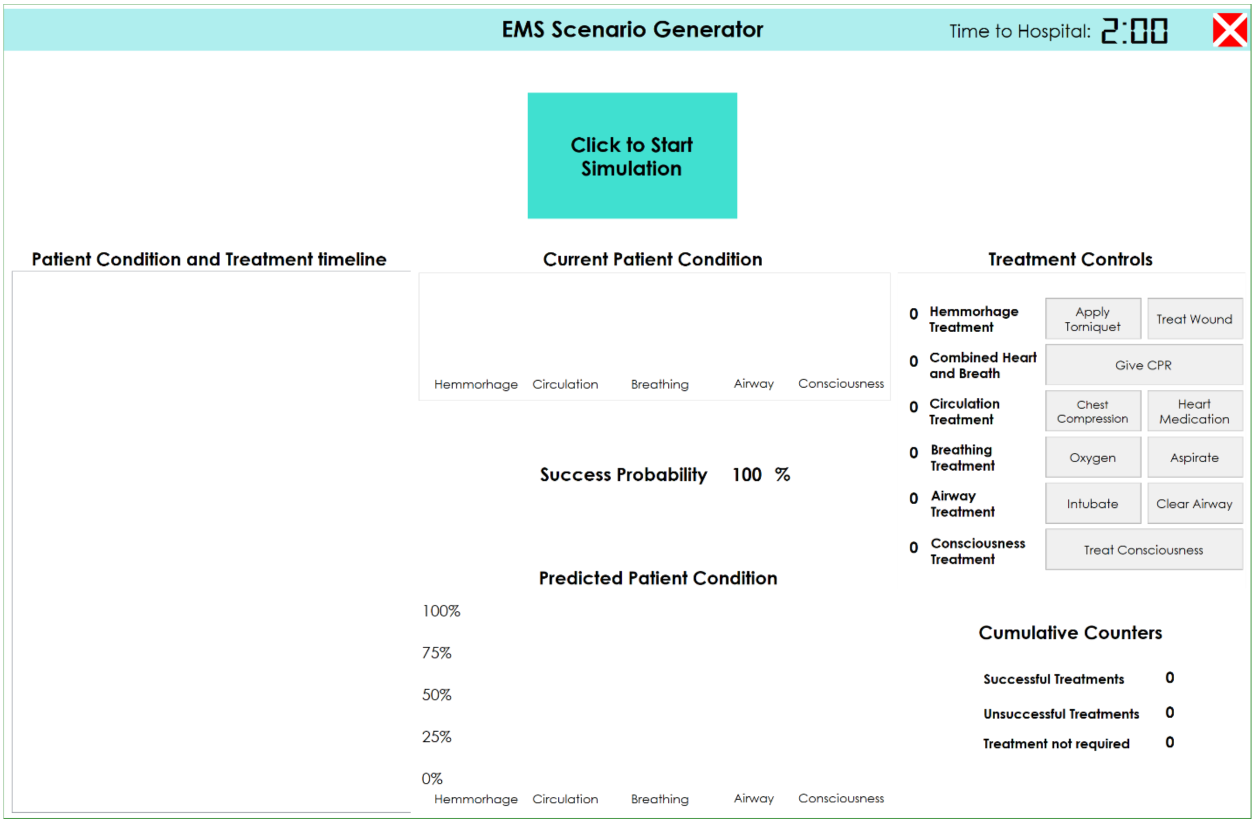


Figure 15. Scenario Generation Form—Prior to Scenario Start and Initialization

Figure 15 gives an overview of the scenario generation interface. The scenario generator screen was modified to reflect the thematic changes throughout the simulation. As well as the appearance changes, the patient treatment timeline section was moved to the left of the screen and action buttons/interactive areas moved to the right. The center was used to display patient status updates. As far as possible, this mental model of the simulator layout was preserved throughout all screens. An overall success probability was displayed to provide feedback to the user on the impact of the applied treatments.

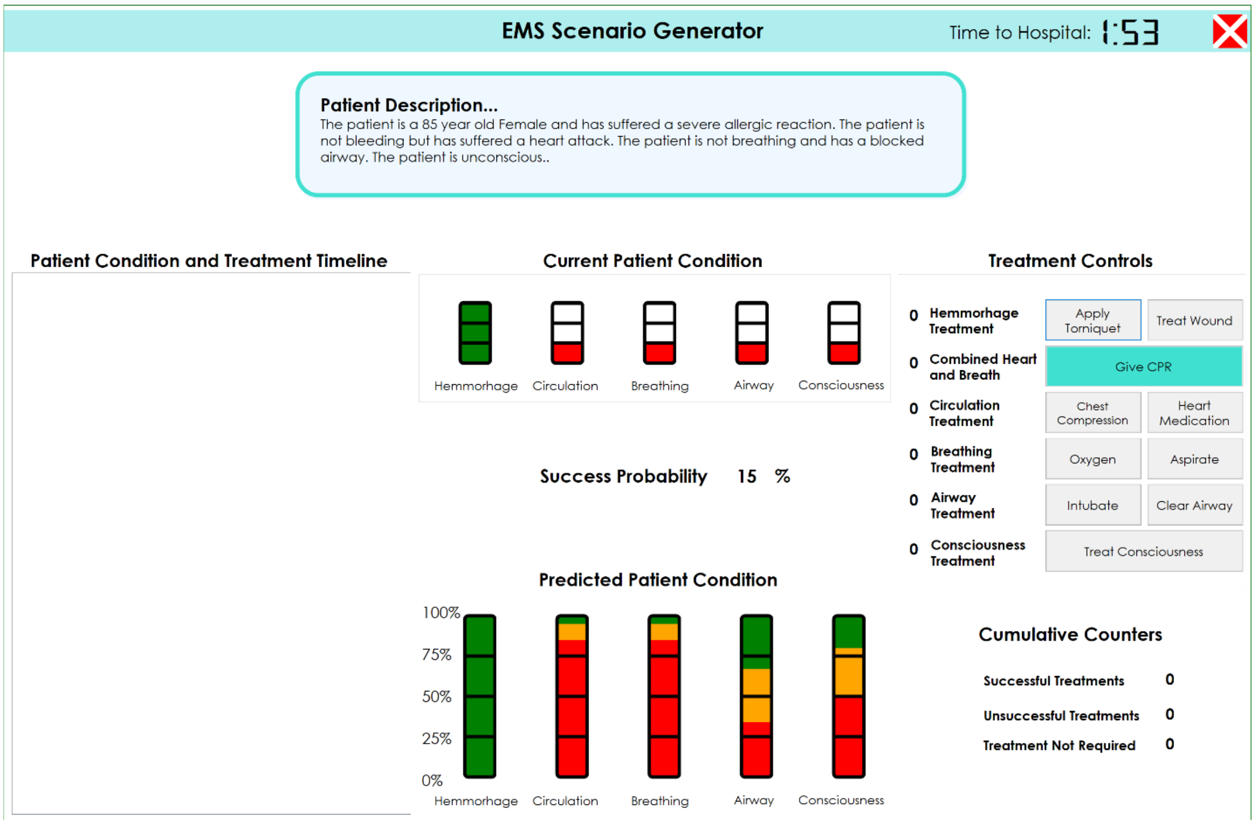


Figure 16. Scenario Generation Form—Post Initialization

Figure 16 reflects the redesigned patient status indicators. The initialized patient description was changed from the initial form, which was a list of attributes, to a more natural language-based information panel. A contextually aware natural-language engine was developed to translate the initialized patient condition variables into a coherent sentence structure. The current patient condition panel was changed from a textbox-based description of the individual characteristics (indicating the condition using 0, 1, or 2, accordingly) to a scale condition indicator. This presented the conditions as a raising and lowering bar where a patient with a characteristic critical in nature is presented as a red bar, analogous to a low battery, while a patient with non-critical injury is represented by an larger orange bar, indicating some degradation in health and a warning. Where patient characteristics are good, the indicator is full and green. While these are all encoded with standard colors for alert states, this is not the sole or primary encoding, allowing color-blind users or those without such developed cognitive models to interpret the patient state quickly.

A simulation timer was introduced to provide the user with an understanding of the time remaining in the scenario generation phase. This is a countdown timer located in the top-right of the simulator. The color of this timer is coded to change as the phase ends—the color turns to green to indicate imminent arrival at the hospital. This color was chosen to reinforce that this is a positive aspect of the simulation and that the user should prepare for the information transfer phase. The timer is also labeled "Time to Hospital" to emphasize that this is an EMS-to-hospital scenario. A panel containing action buttons is located on the right of the screen. The optimal action button is highlighted by the EMS agent, based on the built-in treatment prioritization logic, as shown in Figure 17.

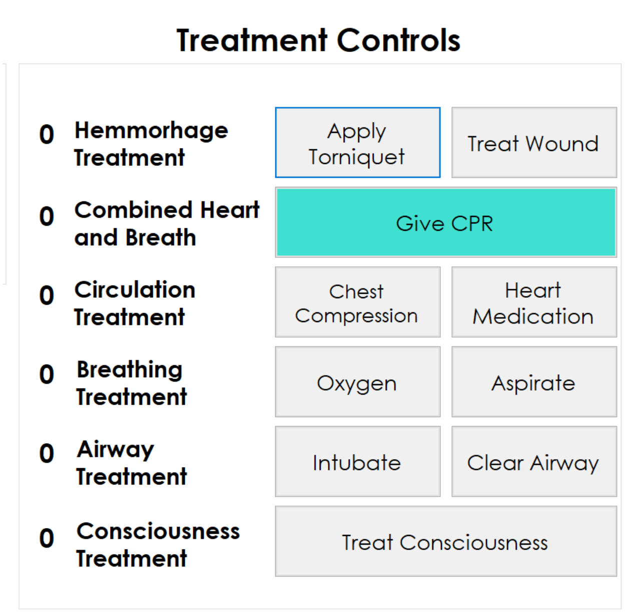


Figure 17. Simulator Treatment Control Panel

The user can choose a different treatment option, if they feel it is necessary. The rationale behind this design approach was to ensure the user remains engaged in the developing scenario throughout the simulation and has an awareness of each treatment applied. A non-interactive scenario development or simple provision of data to input into an information transfer phase would not offer the same realism as a dynamic, interactive scenario. Once the user selects a given treatment, there is a pop-up feedback message displayed to indicate the treatment is being applied. The ongoing treatment is indicated by a rotating pair of arrows, denoting an ongoing process. This was chosen as it is a standard UI element used to indicate an ongoing process of indeterminate time. This should be a part of the users' existing mental models of design interfaces and in line with expectations. At this time, the EMS agent is switched to a "treatment" state and cannot receive any inputs to action different treatments and is also not available to check the patient degradation. The message box implementation is shown in Figure 18.

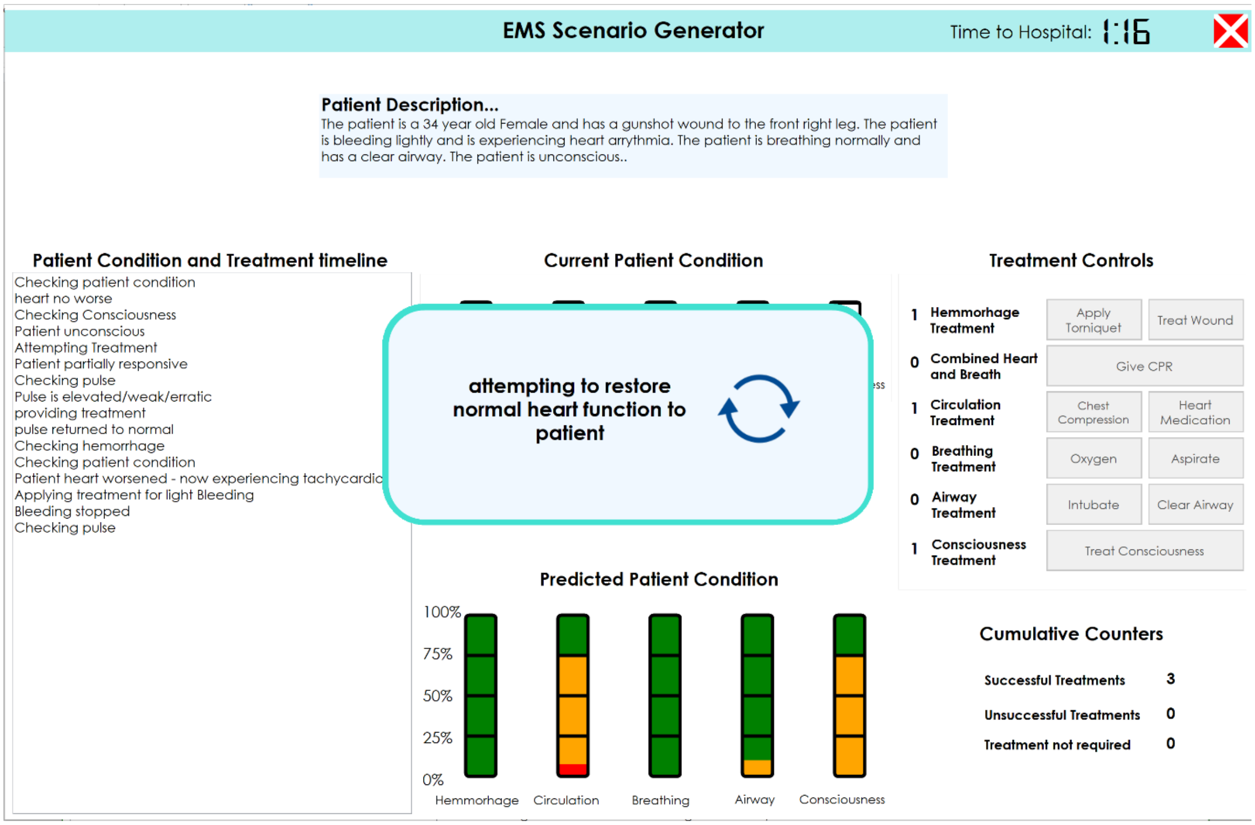


Figure 18. Scenario Generation Form—Displaying Treatment Message

The treatment updates were applied after the treatment pop-up message disappeared. This ensured the updates to the patient condition were presented in an intuitive, predictable manner and enhanced the user's satisfaction with the system. In addition to the standard treatment pop-up message, additional information on the stability of the patient is provided when all patient characteristics are returned to 0. If there is still predicted instability in the patient condition, this is also included in the stability information. This implementation is shown in Figure 19.

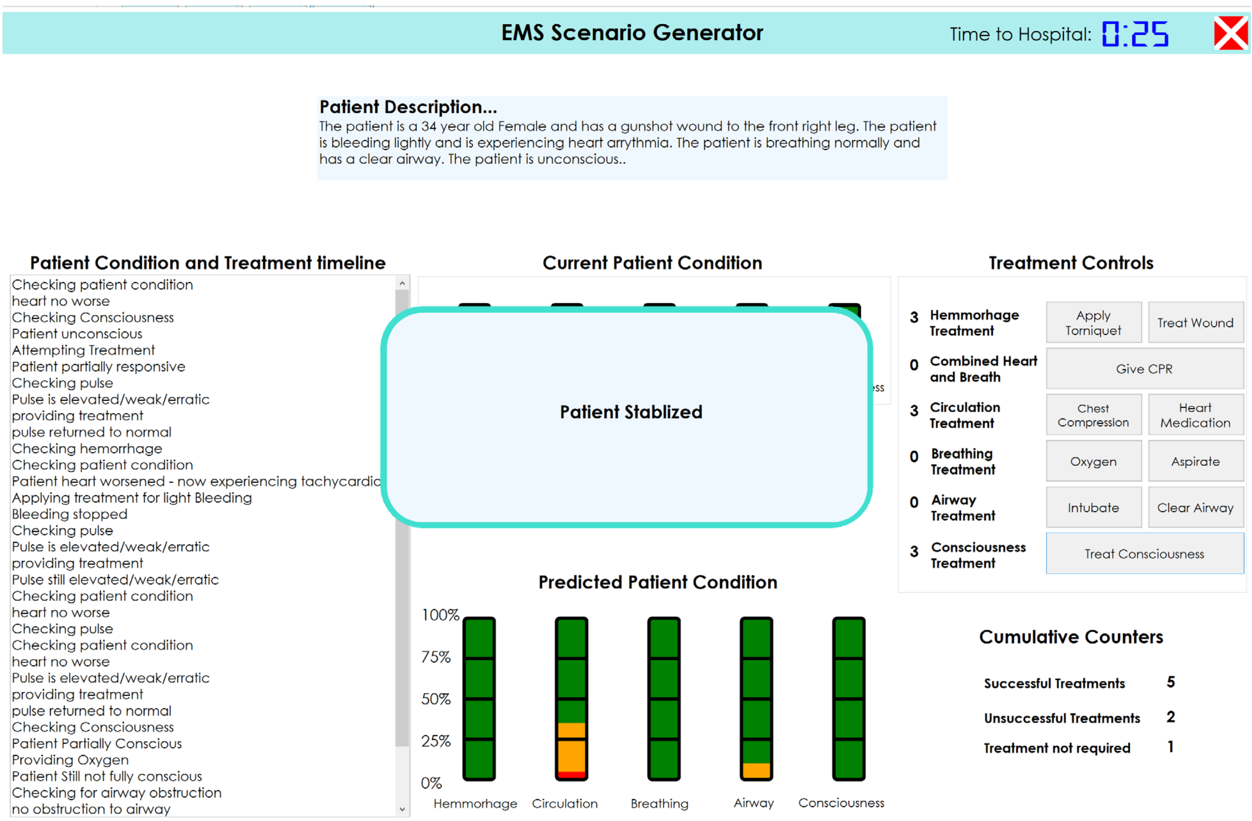


Figure 19. Patient Stability Information Display

The final 10 seconds of the simulation are to enable the user a final opportunity to memorize the important elements of the emergency scenario. At this stage, patient degradation is suspended, and the simulation countdown clock is changed to green to demonstrate the impending transition to the information transfer phase. This element is shown in Figure 20.

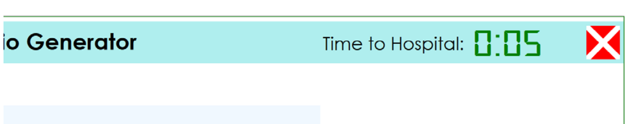


Figure 20. Time to Hospital Display

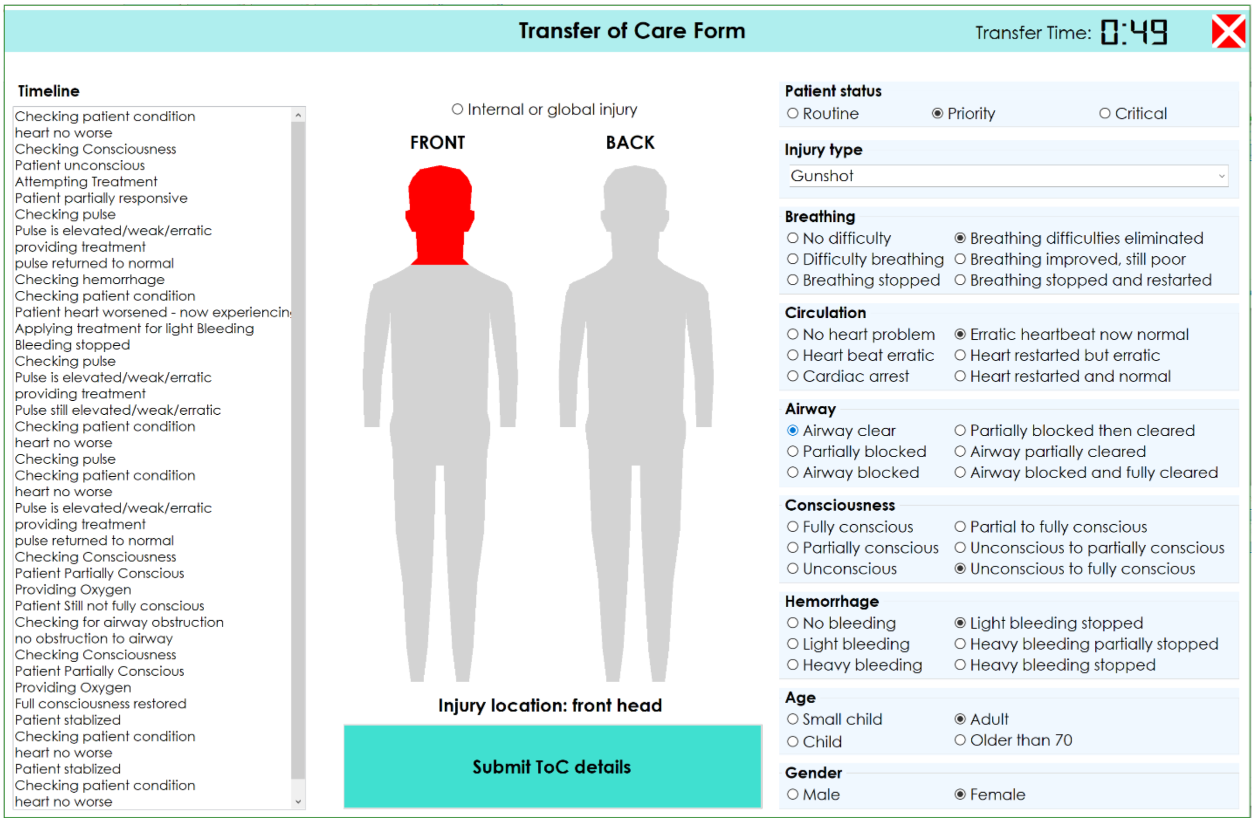


Figure 21. Transfer of Care Form

The Transfer of Care form, shown in Figure 21, has the treatment timeline on the left of the screen as in the scenario generator, although it takes up slightly less screen to allow for the injury location elements. These are actionable "hot key" representations of a human body that are used to indicate the position of the injury. The current implementation allows for only a single injury. In addition to the physical location, there is a button to input the injury location as internal/global. This is to provide a positive input requirement for injuries, such as heart attack, so that there are consistent steps required in the mental model development for all injury types. An injury location confirmation message was added below the body "hot key" representations to ensure the user had clicked on the correct area of the body. This was due to left-right ambiguity or possibility for confusion on the front and back torso representations. More anatomical detail could be provided to reduce ambiguity, but this error is commonly made by humans when viewing mirror images or back-to-front representations.

To minimize data-entry errors outside the scope of this study, a standard multiple-choice style form was utilized for both test scenarios. In the case of the AI-assisted version of the simulation, prompts and warnings were used to help the participant ensure data entry was complete and in line with predictions of patient condition made within the AI. After completion of the standardized Transfer of Care form, the patient state according to the simulation participant is "transferred" and compared to the baseline patient agent status developed in the simulation based on predetermined weighted scores for each patient characteristic.

The Transfer of Care form also incorporated a timer, although this was a stopwatch style timer rather than the countdown implemented in the scenario generation screen. This records the total time taken in the information transfer phase, assumed to be from the point of arrival at the hospital. The optimal time for the information transfer phase is defined in the RLVC Requirements Document (2016) as 2 minutes. After 1minute 30 seconds, the timer turns orange to indicate the 2 minutes is nearly up (see Figure 22); then after 2 minutes, the display turns red and the simulator displays a warning to the user explaining the optimal transfer time has been exceeded (see Figure 23). This phase of the simulation is conducted in real time as opposed to the shortened timescales of the scenario generator phase.

Figure 22. Information Transfer Information Presentation—Time Warning

Figure 23. Information Transfer Information Presentation—Optimal Time Exceeded Alert

Once the trainee has completed the information transfer phase, they are presented with the weighted results to give them immediate feedback on their performance and to reinforce cognitive models built in the simulation. A score for each patient characteristic transferred is given that allows granular interpretation of performance where the trainee can identify specific areas of weakness and develop strategies to improve performance. This immediacy and granularity as well as connection with outcomes are difficult to achieve in the real-world scenarios and underpin the rationale for this simulator. The simulation results page is shown in Figure 24. Results are not currently collated, but long-term trends could be determined by tracking trainee performance over many repetitions of the test. The granularity of the results can then enable targeted training on specific information transfer concepts or areas for improvement. This would not be possible with a more aggregated result.

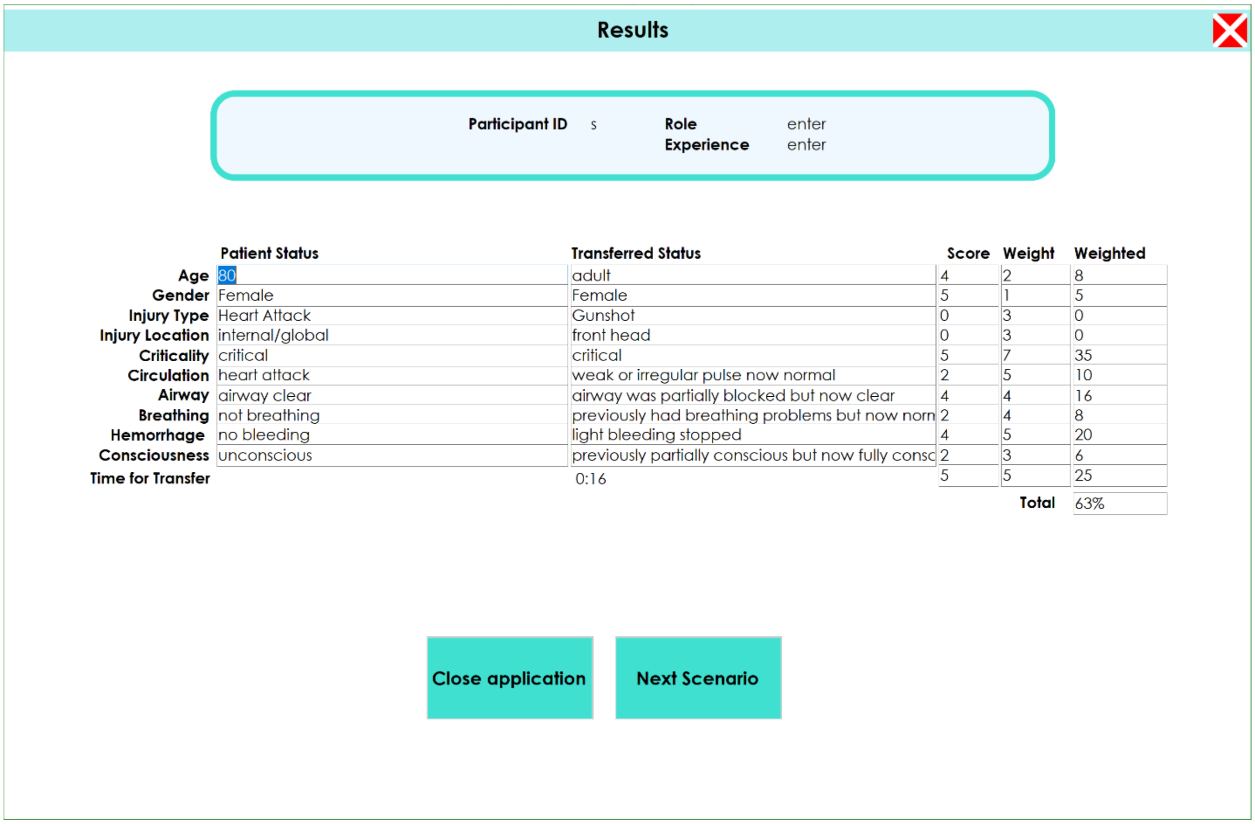


Figure 24. Simulation Results Screen

5.8. Quantification and Supporting Evidence of Rules and Logic Definitions

The full list of references and sources for each of the rules or probabilities defined in the simulation is provided in Appendix C. Where possible, quantitative analysis was used to inform the model, but where this was not possible due to data limitations, alternative sources such as medical journals were used. In some cases, assumptions were made where no supporting data could be found. These cases are highlighted in Appendix C and are identified as specific limitations of the prototype simulator.

6. Results

It was hypothesized that the Agent-Based Simulation would provide a complex, realistic representation of an emergency situation. The simulation will be subject to full human subjects testing in subsequent phases; however, current testing was limited to a verification assessment of the simulation and qualitative assessment of user-interface elements of the design. The expectation was that the simulation would produce situations that were statistically similar, in terms of their output distribution, to the source data.

6.1. Quantitative Verification Method

The statistical components of the model were verified by running the patient agent MDP section of the simulation with the participant interaction requirement removed. These 625 scenarios were performed 10 times to increase the dataset size for statistical comparison to the training dataset. The outcome, or final state in the patient agent, was then compared to outcomes in the NEMSIS database to determine if the patient agent model was statistically representative of the real-world data. The total simulated and expected outcomes (based on NEMSIS data) are shown in Table 15.

Table 15. Verification Testing Results

Patient state at Transfer of Care	**NEMSIS "test" data**	**Simulation data (test)**
All injuries—"Non-Severe"	5113	4735
All injuries—still "Severe" injury	1080	1413
Dead	57	102
Total	6250	6250

The Chi-square test was used to compare the frequencies of the outcomes of the patient simulation with a test dataset taken from the NEMSIS database for the total outcomes and individual injury types. The null hypothesis H_0 is that simulation output frequencies for the possible outcomes are different from the test data, the Alternative Hypothesis H_A is that the simulation and test data are statistically the same. For this test, $\alpha = 0.05$ and a critical value of 5.99 was derived from tables. The Chi-squared value for the test was 165.23, $P < 0.001$; therefore, the null hypothesis is rejected and the simulation is statistically similar to the test data. In addition to this, the simulated outcomes for individual injury types were found to be statistically similar to the test data derived directly from the NEMSIS database.

7. Conclusions

7.1. Conclusions from the Quantitative Verification of Model Utility

The simulation developed in this project can generate complex EMS scenarios and present relevant information to users in a format that allows data to be collected and then transferred in a way that simulates a real-world Transfer of Care scenario. Further testing is required to assess the performance of the simulator, both with and without AI agent assistance to the trainee. The verification of the patient model showed the model is statistically representative of the NEMSIS database in terms of patient outcome at the Transfer of Care point. Despite this, the model over-simulated death cases and under-simulated non-severe cases particularly. Although the distributions that underpinned the patient model in the simulation were derived from the NEMSIS database, other interactions with the rule-based agent could be causing the observed discrepancy. Further investigation of the impact of this finding and possible changes to the agent logic will be explored in the refinement of the simulation.

7.2. Known Limitations of the Simulation

The current known limitations of the simulation are detailed below. These should not be considered exhaustive, but they indicate areas for development in future iterations of the simulation.

- There is no logic to address CPR/breathing treatment with blocked airway.
- No degradation of circulation with breathing.
- Breaks, sprains, etc., are not currently included in the simulation
- Want to individually color code the timeline—to reflect seriousness but can't yet?
- Message saying "patient has stopped responding" when probability of complete improvement drops below a certain threshold?

- No time remaining indication on the treatment pop-up.
- There is no total progress indicator—how many screens left.
- There is no timing indicator on the treatment pop-ups.

7.3. Conclusions on the Implementation of Agent-Based Simulation

The Agent-Based Simulation approach produced complex and dynamic scenarios with a low probability of repetition. The Agent-Based approach, in this case, demonstrated that the stochastic behaviors and interactions between agents were developed with a high level of complexity, meaning that in 1,000 test runs, there were no two scenarios with the same initial conditions, let alone duplication once patient degradation and treatment response were included. Developing a model to generate this degree of entropy using other, more traditional methods would be potentially more time consuming and less likely to produce the desired effect. The Agent-Based architecture configuration was also found to be intuitive in the design stage, allowing the software designer to intuitively understand the allocation of behaviors, states, and their connections in the simulation environment.

7.4. Discussion

While the Agent-Based Simulator was capable of producing the highly complex simulated situations envisaged in the concept, there was a desire to test this against a simulation built using more traditional discrete-event modeling approach. Initially, it was believed that this could be achieved by building a simplified representation of the model, which referenced databases and build events based on the same data used to develop the agents in the Agent-Based variant. Once this task was started, it became clear that producing a discrete-event simulator that was anything like representative of the Agent-Based system would be a large undertaking due to the existing number of potential variables and the reliance on rules generated from large datasets. While this is not objective proof or anything more than anecdotal evidence, it does show the problems inherent in the discrete-event modeling approach. In attempting the design of this second comparison simulator, it became clear that the architectural choices that are intrinsic to, or dependent on, the Agent-Based approach also make the design and development of such a complex simulator easier to conceptualize and implement. For these reasons, it is the belief of the author that Agent-Based Simulation is a much more suitable design framework for such a complex application.

8. Recommendations

Although the current prototype simulator demonstrates the suitability of Agent-Based Simulation to provide a complex, dynamic learning environment that can generate information to be used in human training, many aspects are highlighted in the evaluation of the platform that need to be addressed before a fully functioning Agent-Based simulator could be used in training. The future steps required to implement this are summarized in section 8.1.

8.1. Future Work

To test the impact of an AI assistant on Transfer of Care performance, two separate simulations will be conducted on a representative user population (possibly the WSU community, or EMS professionals). Both simulations will present the participant with a medical emergency situation; however, one will include access to the virtual AI assistant, and the other will rely on the participant for all aspects of information transfer decision making and require fully manual input. The Transfer of Care form in the simulation will be the same in both cases.

A single independent variable, within-subjects assessment will be conducted. There will be two levels of the independent variable; access to the AI assistant or not. Participants will be asked to conduct the simulation with and without the AI assistant in the same test sitting, but the order in which the simulation is run will be counter-balanced to remove experimental bias. The dependent variables of the study will be both qualitative and quantitative. The scoring method defined in section 5.6.1 provides an outline for how the information transfer performance will be quantified. Although this scoring method is designed to be adaptive, the control of the initial scenario within the experiment to the example of a single gunshot wound to the leg. This will fix much of the otherwise dynamic nature of the assessment framework to ensure that results are comparable between subjects, or at least to minimize the repetition needed in the experiment. In addition, NASA TLX and SART questionnaires will be used to assess workload and Situational Awareness (SA), respectively. These metrics will be combined with a subjective self-assessment of the participant's performance in the simulation asking the user to assess their performance in timeliness, accuracy, and quality of information transfer on a Likert scale. The subjective questionnaire is given in Appendix D.

A one-way ANOVA will be conducted on each of the quantitative performance metrics to determine if there was a statistically significant difference between the mean performance with AI (μai) and without AI (μp) and hence the effect on performance associated with the AI assistant.

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APPENDIX A

TRANSFER OF CARE PROCEDURE

Transfer of Care procedure as identified in the RVLC Requirements Document (2016).

1. Report/transfer of care
   Some semblance of the following statements must be stated in order for transfer of care to occur. Exact wording is yet to be agreed upon and discussed.
   a. "I am giving report to (receiving medical personnel)."
   b. "The patient's name is _________."
   c. "The patient's age is ________. "
   d. "The patient's weight is __________. "
   e. "The patient's gender is ________."
   f. "The incident occurred at (specific time)."
   g. "The mechanism of injury is (type of accident)"
   h. "I have performed (list assessments performed and medical findings)"
   i. "I have performed the following interventions: (associated interventions with the findings)"
   j. "The patient has IV access."
      i. "The patient has been given (volume and type of medications)."
   k. "The patient's vital signs are:"
      i. list state of consciousness, (Glasgow Coma consciousness)
      ii. list heart rate
      iii. list blood pressure
      iv. list respirations
      v. list oxygen saturation
   l. Additional information forthcoming/other associated information.

APPENDIX B
TASK ANALYSIS

Hierarchical Task Analysis (HTA)

The HTA conducted during the study is detailed in Table B.1.

Table B.1 Hierarchical Task Analysis

0 EMS Transfer of Care to triage professional Plan 0.	
1. Assess patient—throughout emergency situation Plan 1. Do 1.1 and 1.2—repeat 1.0, 2.0 and 3.0 as needed	
	1.1 Visual Inspection of Patient condition Plan 1.1. Do 1, 2 then 3 in sequence 1.1.1 Check outward signs of consciousness, hemorrhage, breathing 1.1.2 Consult electronic heart/blood pressure indication 1.1.3 Verbal consultation with patient if able. 1.2 Recall prior condition Plan 1.2. Do 1, then 2 in sequence 1.2.1 Recall previous patient condition from chart/record if available 1.2.2 Recall from memory if not on chart and recall is possible
Build mental picture of patient condition—throughout emergency situation Plan 2. Do 1, 2, if mental picture is insufficient repeat 1.1 and 1.2. Do 2.3 and 2.4 !	
	2.1 Determine current status 2.2 Determine past status 2.3 Establish perceived condition delta 2.4 Determine potential improvement/degradation probability
3. Perform Treatment—throughout emergency situation If 2 requires Plan 3. Do 1-2-3-4,	
	3.1 Establish appropriate treatment 3.2 Execute treatment 3.3 Check effectiveness of treatment 3.4 Record treatment
4. Transfer information—on arrival at primary care facility Plan 4. Do 1, iterate through 2-3-4, 5 for all characteristics repeat from 3 if error detected	
	4.1 Identify Triage Nurse/appropriate handoff professional 4.2 Recall patient status 4.3 Verbal transfer of individual patient characteristic 4.4 Await accurate confirmation through talkback protocol from receiving agent. 4.5 Check for error in talkback protocol 4.6 Once complete and content with accuracy and completeness of information transfer conduct formal hand over, including paperwork.

APPENDIX C

SUPPORTING EVIDENCE FOR SIMULATION RULES

The following tables summarize the rules and definitions used in the models within the agents used in the simulation. These values and probabilities define each individual transition of state or assignment of property within the model. The evidence is also summarized in the tables and this column is color coded to indicate the level of confidence in the associated sources/evidence. The rationale behind this color coding is defined in Table C0.1.

Table C0.1. Evidence Color Code Rationale

Green	Orange	Red
Quantitative data derived from real-world sources accompanied by analysis of validity and verification	Qualitative or subjective evidence from a reputable source	Assumptions based on secondary data and assumptions—requires further evidence for a verifiable simulation

C1 Patient Initialization

Table C1.1 contains the summary of the supporting evidence and sources for patient initialization rules in the prototype simulator.

Table C1.1 Supporting evidence for patient initialization rules.

Rule Category	Definitions/Quantifications	Evidence/source
Age Distribution v Wound Type	**Gunshot:** Small child – Child – Adult – Over 70 –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha =0.05 p<0.001
	Blunt Force Trauma: Small child – Child – Adult – Over 70 –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha =0.05 p<0.001
	Drowning: Small child – Child – Adult – Over 70 –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha =0.05 p<0.001
	Heart Attack: Small child – Child – Adult – Over 70 –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha =0.05 p<0.001
	Allergy: Small child – Child – Adult – Over 70 –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha =0.05

		p<0.001
Define Probabilities of Characteristics V Wound Type	**Gunshot:** Hemorrhage – Circulation – Consciousness – Breathing – Airway –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha = 0.05 p < 0.001
	Gunshot: Hemorrhage – Circulation – Consciousness – Breathing – Airway –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha = 0.05 p < 0.001
	Gunshot: Hemorrhage – Circulation – Consciousness – Breathing – Airway –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha = 0.05 p < 0.001
	Gunshot: Hemorrhage – Circulation – Consciousness – Breathing – Airway –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha = 0.05 p < 0.001
	Gunshot: Hemorrhage – Circulation – Consciousness – Breathing – Airway –	**NEMSIS Database** 1M sample training 1M sample test **Verification:** **Chi-squared** alpha = 0.05 p < 0.001

C2 Patient Degradation

Table C2.1 contains the summary of the supporting evidence and sources for patient degradation rules in the prototype simulator.

Table C2.1. Supporting Evidence for Patient Degradation Rules

Rule	Variables/definitions	Evidence/source
Hemorrhage Degradation: Stochastic rules for how hemorrhages degrade with time	Low Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Kragh et al. (2008).
	Low Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Kragh et al. (2008).
	High Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Kragh et al. (2008).
	High Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Kragh et al. (2008).
Consciousness Degradation: Stochastic rules for how consciousness degrades with time if hemorrhage present	Low Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)

	Low Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	High Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	High Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
Circulation Degradation: Stochastic rules for how circulation degrades with time if hemorrhage present	Low Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	Low Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	High Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)

	High Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
Circulation Degradation: Stochastic rules for how Circulation degrades with time	Low Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	Low Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	High Initial Hemorrhage—short term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
	High Initial Hemorrhage—long term Stopped to high: Low to high: Stopped to high:	Source: (Carr, 2016)
Consciousness Degradation: Stochastic rules for how Consciousness degrades with time	Degradation dependent on other states within the patient agent.	RLVC Requirements Document (2016)

C3 Treatment Response

Table C3.1 contains the summary of the supporting evidence and sources for patient degradation rules in the prototype simulator.

Table C3.1. Supporting Evidence for Patient Treatment Response Rules

Rule	Definition	source
Hemorrhage recovery	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Hemorrhage recovery after previous treatment and degradation	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Hemorrhage recovery probability degradation per failed attempt	High level	NEMSIS (high level/low level differentials are assumed
	Low level	NEMSIS (high level/low level differentials are assumed
Circulation recovery	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed

	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Circulation recovery after previous treatment and degradation	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Circulation recovery probability degradation per failed attempt	High level	NEMSIS (high level/low level differentials are assumed
	Low level	NEMSIS (high level/low level differentials are assumed
Airway recovery	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to Low level (no change)	NEMSIS (high level/low level differentials are assumed
Airway recovery after previous treatment and degradation	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed

	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Airway recovery probability degradation per failed attempt	High level	NEMSIS (high level/low level differentials are assumed
	Low level	NEMSIS (high level/low level differentials are assumed
Breathing recovery	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Breathing recovery after previous treatment and degradation	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Breathing recovery probability degradation per failed attempt	High level	NEMSIS (high level/low level differentials are assumed
	Low level	NEMSIS (high level/low level differentials are assumed

Consciousness recovery	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Consciousness recovery after previous treatment and degradation	High level to low level	NEMSIS (high level/low level differentials are assumed
	High level to cured	NEMSIS (high level/low level differentials are assumed
	Low level to cured	NEMSIS (high level/low level differentials are assumed
	High level to high level (no change)	NEMSIS (high level/low level differentials are assumed
	Low level to low level (no change)	NEMSIS (high level/low level differentials are assumed
Consciousness recovery probability degradation per failed attempt	High level	NEMSIS (high level/low level differentials are assumed
	Low level	NEMSIS (high level/low level differentials are assumed

APPENDIX D

STRUCTURED SME REVIEW (POST TASK ANALYSIS)

Simulation

Does the simulation represent suitably complex transfer of care scenarios?

Does the transfer form represent, as far as possible, the information requirements when transferring information?

Does the Simulation timing represent, in so far is possible, the time pressure associated with Transfer of Care?

Does the feedback provided by the system give improved understanding of the Transfer of Care process?

UI elements—SUS.

AI elements

Do the AI elements within that specific part of the sim improve the information transfer process?

Scoring System

Does the scoring system reflect the relative severities of potential incorrect or missing information?